MODELING OF HIGH VOLTAGE POWER TRANSFORMER WINDING FOR PARTIAL DISCHARGE TEST

A Thesis submitted in partial fulfilment

Of the Requirements for the Award of the degree of

Master of Technology

In

Power Control and Drives

By

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Under the Guidance of

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CERTIFICATE

This is to certify that the thesis entitled, **"Modelling of high voltage power transformer winding for partial discharge test"** submitted by **Sachin Dev Barman (Roll No. 211EE2126)** in partial fulfillments for the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in **"Power Control and Drives"** during 2012-2013 at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any degree or diploma.

Date: 22/05/13

Prof. S. Karmakar
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CONTENT

ABSTRACT

In the power system network, power transformer is plays an important role for maintaining the constant system operating voltage throughout its long service life. Most of the high voltages transformers are manufacture with different kind of solid insulation (i.e., paper, mica, ceramic insulator, and spacer etc.) to withstand such high voltage stress. Therefore, insulation condition monitoring of such transformers are the utmost important routine work for every power engineers to increase its reliability. It is studied that, partial discharge (PD) is one of the causes of insulation failure in high voltage power transformer winding as it is suffers high voltage stress throughout the service period. Therefore, it is very important to early detection of PD inside the transformers for reliable operation of the high voltage equipment and avoids massive failure in the power system network. In this study, a simulation model is developed for disc type power transformer winding to simulate the PD activity inside the transformer using the MATLAB simulink environment. In addition, the PD activity inside a prototype transformer has been observed in the high voltage laboratory using acoustic emission technique.

LIST OF ABBREVIATIONS

IEC	International Electrotechnical Commission
PD	Partial Discharge
HV	High Voltage
AST	Auto Sensor Test
AE	Acoustic emission

LIST OF SYMBOLS

Symbol

C_a	Capacitance of air
C_s	Capacitance of solid
E_a	Electrical field of air
E_s	Electrical field of solid
L_i	Leakage inductance
R_i	Loss due to insulation between adjacent winding section
C_{si}	Coil to coil capacitance
C_{gi}	Coil to ground capacitance
C_{gp}	Capacitance of the region where the discharge takes place
C_b	Capacitance of the region which is in series with C_{gp}
C_a	Capacitance of the rest region in the dielectric
R_d	Resistance of the detection circuit
L_d	Inductance of the detection circuit
C_d	Capacitance of the detection circuit

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CHAPTER 1

INTRODUCTION

Introduction

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Chapter-1
INTRODUCTION

1.1 INTRODUCTION

Power transformers have been in service for many years under different environmental, electrical, and mechanical conditions. They are very expensive and form a high percentage of the investment of a power system [1]. Extending transformer life as long as possible is not only economically valuable, but also prevents lost revenues when power outages occur. The power outages are a result of ageing processes, electrical overstressing or presence of defects introduced during manufacture [2]. PD is one of the major reasons for the short life span of power transformers. PD might occur anywhere inside a transformer particularly along the transformer winding and the discharge signal can propagate along windings to the bushing and neutral to earth connections. Therefore, the identification of a PD source as well as its location is essential to ensure that PD monitoring allows evaluation and maintenance processes to be carried out effectively [3].

1.2 LITERATURE REVIEW

In the last century, when the high voltage technology was introduced for electrical power generation and transmission system, Partial discharges have already been recognized as a harmful source for the insulation aging in the high voltage power apparatus. Different techniques are developed for detection, measurement and behavior study of PDs inside the transformer winding. Many authors have presented their work about the detection and measurement of PDs. Z.D.Wang, P.A.Crossley and K.J. Cornick explained the various issues related to the PD propagation in power transformer. They discussed about the general simulation model of transformer windings. They also discussed about how to calculate the parameter of the transformer winding [4]. Mehdi Nafar, TaherNiknam and Amir hosseinGheisari have proposed a work for locating partial discharge in power transformer using correlation coefficient. They used disk winding for partial discharge fault detection and location in transformer winding [5]. AsgharAkbari, Peter Werle, HosseinBorsi and Ernst Gockenbach have done transfer function based partial discharge localization in power transformer [6]. M. S. AbdRahman, L. Hao, P. Rapisardo and P. L. Lewin have proposed a work on partial discharge simulation for a high voltage transformer winding using a model based on geometrical dimension. They have made a lumped parameter network model for transformer winding. And also done the experimental work for simulate the PD phenomena using signal generator inside transformer winding and after that they are comparing both experimental and simulation result [7].

1.3 MOTIVATION AND OBJECTIVE OF THE THESIS

1.3.1 MOTIVATION

The appearance of PDs is a problem for insulation failure of power transformer winding used in power plant. It is seen that most of the transformer winding are manufactured with great care so that no impurity is added in the winding insulation. But some small amount of impurity is always present during it manufacturing process. The impurities are in the form of solid, liquid or gas. During the manufacturing process of such winding insulator the impurity is present in the form of air bubble which creates a weak zone inside the winding. Most of the failure of such insulation occurs due to presence of PD at the weak zones with high voltage stress in the transformer winding. Therefore, detection and the measurement of such PD s are very much important task to avoid the catastrophic failure of the power transformer as well as reliable operation of the transformer throughout its service period.

1.3.2 THE MAIN OBJECTIVE OF THE THESIS

- To observe the PD phenomena inside the transformer winding using MATLAB based model.
- De-noising of the observed PD signal.
- To find out the
    - PD intensity variation with variation of the PD model.
    - Frequency content of obtained PD pulses.
- To observe the PD activity inside a prototype transformer in the high voltage laboratory using acoustic emission technique.
- To find out the parameters of the observed PD pulses.

1.4 ORGANIZATION OF THESIS

This thesis organized into six different chapter including introduction

Chapter 1: In this chapter includes the introduction, motivation & objective of the project. It also covers the literature review on partial discharge characteristic as well as organization of the thesis.

Chapter 2: This Chapter describes the concept of partial discharge and the necessity of partial discharge detection in transformer. It’s classification in transformer and the effects of partial discharge in transformer winding.

Chapter 3: This chapter discussed about the modelling of partial discharge inside power transformer winding. It includes transformer winding model and the PD model presence in the winding and the detection circuit to detect the PD signals. Also describe the MATLAB model for PD measurement.

Chapter 4: This chapter contain simulation result of PD and analysis of the developed model has been discussed. It covers the detection of PD signal, frequency contain of obtained PD pulse, rise time and fall time calculation of PD pulse.

Chapter 5: In this chapter experimental setup is discussed for detection of PD signal using acoustic emission analysis in model transformer and about the sensor that has been used and experimental results are shown in both figure and table form.

Chapter 6: Finally this chapter concludes the thesis work and scope for the future work is discussed in brief.

CHAPTER 2

CONCEPT OF PARTIAL DISCHARGE

Chapter-2
CONCEPT OF PARTIAL DISCHARGE

2.1 INTRODUCTION

IEC (International Electrotechnical Commission) standard 60270 has defined partial discharge as a localized electrical discharge that only partially bridges the insulation between conductors and which can or cannot occur adjacent to a conductor. Partial discharges are in general a result of local electrical stress concentration in the insulation or on the surface of insulation. PD within an insulating material is usually initiated within gas filled voids within the dielectric. since the dielectric constant of the void is considerably less than the surrounding dielectric, the electrical field across the void is significantly higher than that across an equivalent distance of dielectric [8]. If the voltage stress across the void is increased above the corona inception voltagefor the gas within the void, PD activity will start within the void.When PD is occur in gases, it is called as a corona discharge. There are some similarities between corona and PD. They both are precursor of total breakdown, they take place where the voltage gradient is higher and the discharging current is very small in relation to the final breakdown current [1]. The differences are also there,Corona discharge takes place in the surrounding air and it causes no permanent damage. When the voltage is removed, the air becomes normal again. PD causes permanent damage. Corona discharge is visible and audible but PD is not. PD can occur in both AC and DC supply [9].It is different from fully discharge because of that equipment is not permanentlydamage. PD is partially damage, it is just a starting of failure in high voltage equipments, and therefore it is called PD. In general the duration of PD pulse is much less then 1μs. PD activity is usually observed in high voltage power equipments like power-transformers, machines, switchgears, underground cables,etc [10].

2.2 NECESSITY OF PARTIAL DISCHARGE DETECTION IN TRANSFORMER

The process of manufacturing transformer winding insulation structure involves several stages starting from selection and preparation of raw material, processing of raw material, thermal or chemical treatment if essential etc. The entire process of providing electrical insulation in a winding involves man, material, machines and different environmental conditions. It is therefore very difficult to achieve a perfect electrical insulation without defects as it may get contaminated during the process of manufacturing. The influence of surrounding thermal, electrical, mechanical and environmental stresses may also cause defects in electrical insulation during its operation. So some impurity is their due to presence of air bubble in winding. It weakens the insulation region and responsible for appearance of PDs. The region behind it is, dielectric constant of the void is less than of its surrounding. So it causes insulation failure in high voltage power transformer winding. Partial discharge has less magnitude but it is responsible for degradation. Due to event of discharge ultimately failure occurs in the insulation of winding. Because of the above reason PD detection and measurement is necessary for predication of insulation life for power transformer winding.

2.3 CLASSIFICATION OF PARTIAL DISCHARGE

Partial discharge is mainly divided in two parts-

(a) External Partial Discharge

External partial discharge takes place outside of the power equipments. Such types of discharges occur in overhead lines and armature etc.

(b) Internal Partial Discharge

The discharges which take place inside of the power equipments are internal partial discharge. Partial discharge is defined as a localised discharge process in which the distance between two electrodes is only partially bridged i.e., the insulation between the electrodes is partially punctured. Partial discharges may originated directly at one of the electrodes or occur in a cavity in the dielectric some o the typical partial discharges are [11, 12]

(i) *Corona discharge:* Corona discharge takes place due to non-uniformity of electric field on sharp edges of conductor subjected to high voltage. The insulation supplied for such type of discharge is gas or air or liquid [11]. Such type of discharges appears for a long duration around the bare conductor. They are not attacking directly to the insulation system like internal and surface discharges. just by the indirect action of ozone formed by corona deteriorates insulating materials used.

(ii) *Surface discharge:* Surface discharges takes place on interfaces of dielectric material such as gas/solid interface as gets over stressed times the stress on the solid material.

This may occur in bushing, end of cable, any point on insulator surface between electrodes (high voltage terminal & ground) [11]. The occurrence of such discharge depends on various factors such as

- Permittivity of the dielectric material
- Voltage sharing between the conductors
- Properties of the insulating medium where PD occur

(iii) *Treeing channel:* High intensity fields are produced in an insulating material at its sharp edges and it deteriorates the insulating material [11].That is responsible for production of continuous PD, called as Treeing channel.

(iv) *Cavity discharge:* The cavities are generally formed in solid or liquid insulating materials. The cavity is generally filled with gas or air. When the gas in the cavity is over stressed such discharges are taking place [11].

2.4 PARTIAL DISCHARGE IN SOLID INSULATION

In electrical breakdown of a medium has been defined as an irreversible process in which a medium under consideration is unable to support the applied external electric field. This definition is not strictly applicable for an insulation system. The breakdown therefore, shell is re-defined keeping in view the components thereof. The effect of the relatively weaker dielectric or a defect can be detailed as under. In Fig. 2.1 the expression for capacitances C_a, C_s and the electrical fields E_a, E_s with usual notation can be written as [13]

$$(E_a/E_s) = (C_a/C_s)$$

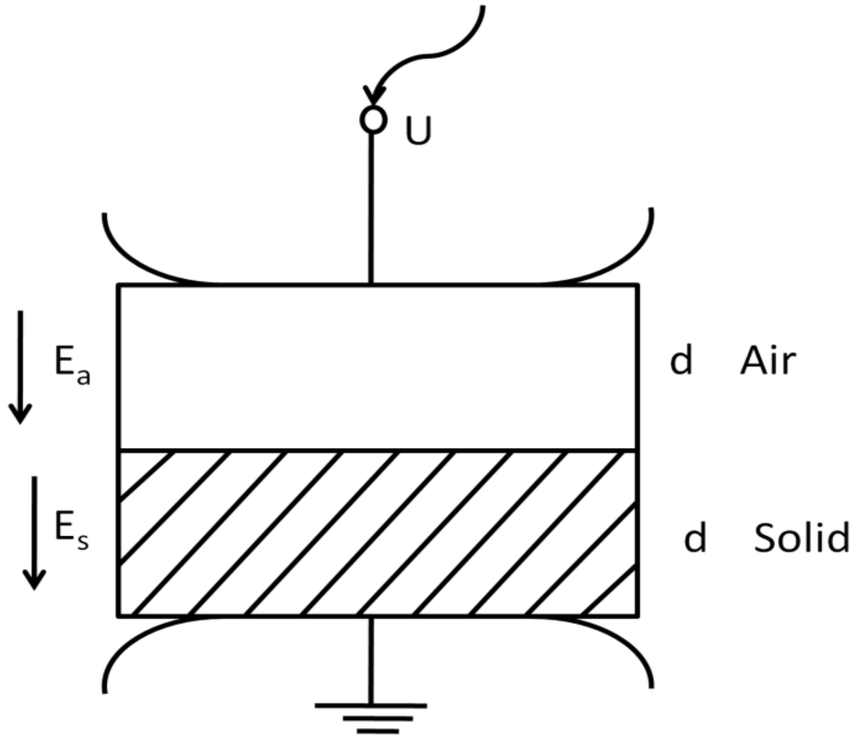


Figure 2.1: Air gap and solid insulation.

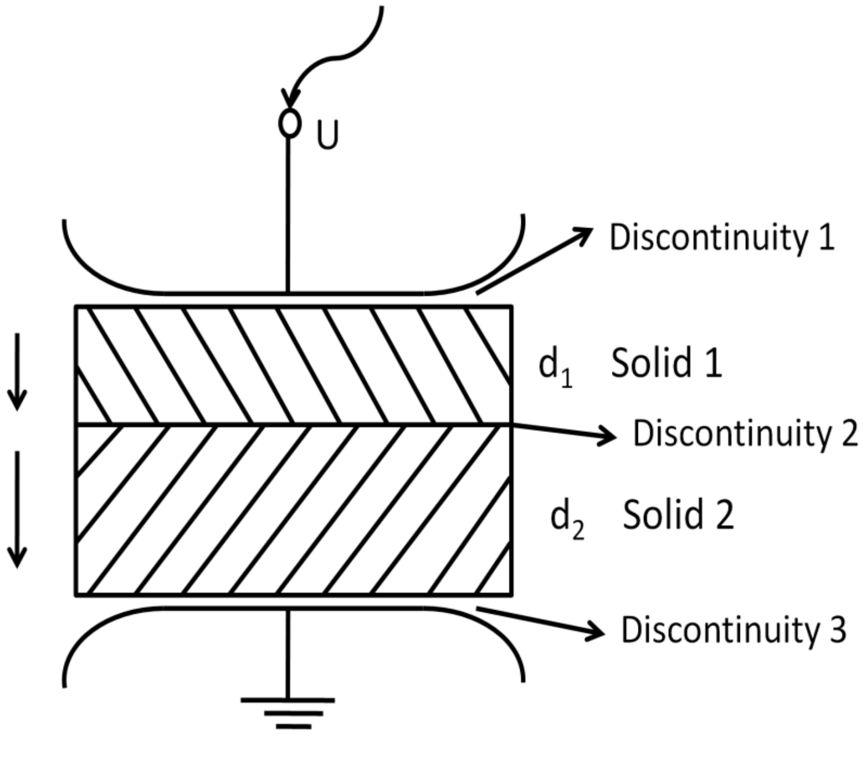


Figure 2.2 Two different solid insulation media.

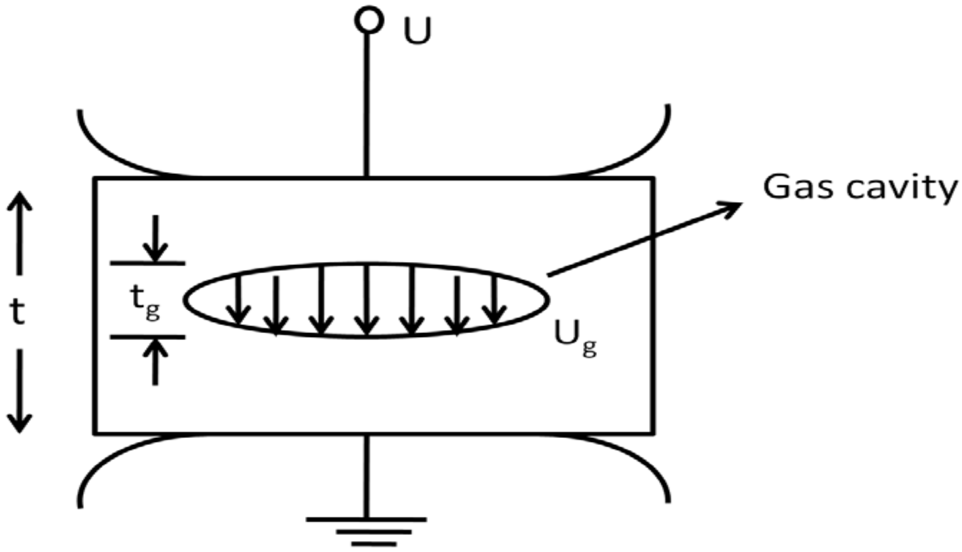


Figure 2.3 Gas cavity in solid insulation.

It is seen from (1) that the air medium is stressed more than the solid insulation. If the stress is sufficient enough to cause breakdown of the air, an electric spark is generate in the air medium. Since the spark or electrical discharge is confined only to the weaker component, it is called a partial discharge (PD). Similarly unintentionally introduced gaseous media either in series or in parallel with dielectrics as shown in Fig. 2.2 may cause internal discharges in the air space. In Fig. 2.3 an air filled cavity situated in the insulation is also electrically stressed in excess of the surrounding medium and a partial breakdown initiates in the cavity.

2.5 EFFECT OF PD IN TRANSFORMER WINDING

PD is the main reason for degradation of insulating material and responsible for breakdown in winding insulation. The occurrence of repetition rate of discharge is the reason for mechanical and chemical degradation of transformer winding. The conductivity property of insulating material rises due to chemical change in the dielectric. PD generates energy in the form of heat. Heat energy is the main reason for degradation of insulation this effect is called thermal effect for high voltage power transformer. The deterioration of insulation of the insulation can be known by monitoring the PD activity and it should be monitored time to time by power engineer.

2.6 PD DETECTION METHODS

There are various methods are explored for the PD measurement based on both electrical and non-electrical phenomenon. The methods which have been commonly known for measurement of PDs are,

(i) Optical detection method
(ii) Acoustic detection method
(iii) Electrical detection method

2.6.1 OPTICAL DETECTION METHOD

In optical detection method light is dissipated in the form of ionization, excitation process during the appearance of discharge. The discharge of light is dependent on the insulating medium used and other parameters like temperature and pressure. Transparent type of insulating material is applicable for this detection method. So some complexity arises in case of implementation in high voltage transformers due to opaque nature of mineral oil.

2.6.2 ACOUSTIC DETECTION METHOD

In acoustic detection method, acoustic sensors are placed outside of the high voltage equipment for detection of PDs [14, 15]. The acoustic method is effective for perceiving and encoding the acoustic Signal generated during a partial discharge event. Acoustic methods have many advantages over other methods. Acoustic methods are unaffected to electromagnetic interference (EMI), which can reduce the sensitivity of electrical methods. The limitation of this detection method is the nature of acoustic wave propagation is complicated due to the use of non-homogeneous device like high voltage transformer. This method is widely applicable for detection of the different types of PD, finding the location of insulation failure. The difficulty arises behind this method is requirement of sensitivity.

2.6.3 ELECTRICAL DETECTION METHOD

Electrical detection method is one of the most popular methods in HV power equipment for partial discharge measurement. Electrical detection method has been used to simulate the measurement of PDs in the model transformer. It focuses on appearance of the current and voltage pulse created by the current streamer in the void and impurities [18]. The pulses are less than one second and variation of frequency components in the range of KHz, The shape of the pulse and occurrence of phase location within the ac cycle gives the information about type of PD and information about insulation failure. Time domain recording device is used for observation of partial discharge impulses in this detection method. Different signal processing methods are applicable for identification/detection of PD signal. This method is also applicable for online electrical PD detection. Broadband and narrow band electrical noises are found during the operation of HV power equipment. It is not easy to divide those electrical noises and PDs. The impulses which are received in this detection method depend on the geometry of high voltage transformers. This method has several drawbacks but has wide application in power plant which helps the power engineer and technician by giving necessary and important information regarding the characteristic, appearance of different type of partial discharge as well as about the occurrence of insulation failure in high voltage power equipment like transformer, generator, cable etc.

CHAPTER 3

MODELING OF PARTIAL DISCHARGE INSIDE POWER TRANSFORMER WINDING

Equivalent circuit of the transformer winding

Three capacitance model of insulation winding with void

Circuit for detecting PD signal in winding insulation

Simulation model of high voltage transformer winding

Chapter-3
MODELING OF PARTIAL DISCHARGE INSIDE POWER TRANSFORMER WINDING

3.1 EQUIVALENT CIRCUIT OF THE TRANSFORMER WINDING

In the range of frequency associated to PD, the transformer winding behaves as a complex ladder network consisting of inductances, capacitances and conductance. For PD evaluation, a model is required which describes the physical dimensions of windings as precisely as possible within the acceptable frequency range. The detailed model shown in Fig.3.1 has been used for interpreting the high frequency behaviour of transformer coils [5]. The simulation model is an equivalent RLC circuit network based on the theory that should have the same external circuit behaviour as that of the transformer winding. For PD localization and evaluation applications, usually it is enough to locate the disk unit of the winding in which PD has occurred. Therefore the number of the RLC units has been chosen equivalent to the number of coil sections. Thus each winding section is considered as a black-box represented by a RLC unit**.**

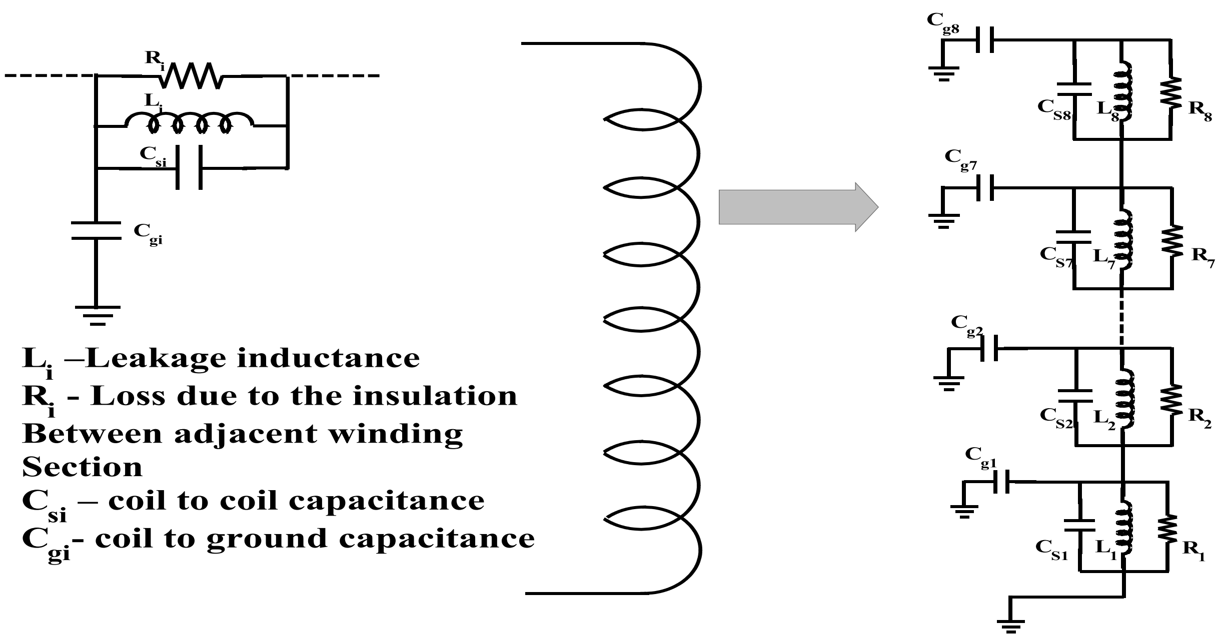


Figure 3.1: Electrical equivalent circuit of the transformer winding

3.2 THREE CAPAPTANCE MODEL OF INSULATION WINDING WITH VOID

A void is created in the transformer winding to generate partial discharge. This void results in a 3-capacitance model as shown in Fig. 3.2. It is used to analyze the PD pulse current that appears at outer electrodes. The capacitance of the region where the discharge takes place is C_{gp}. The capacitance of the region which is in series with C_{gp} is C_b and the capacitance of the rest region in the dielectric is C_a. Rest region of dielectric (C_a) is the region of insulator that is not infected by PD and also it is not series with the cavity. When discharge takes place in C_g, the current I_d will be produced in external terminals [5, 16]. In Fig. 3.2 C_a>>C_{gp}>C_b.

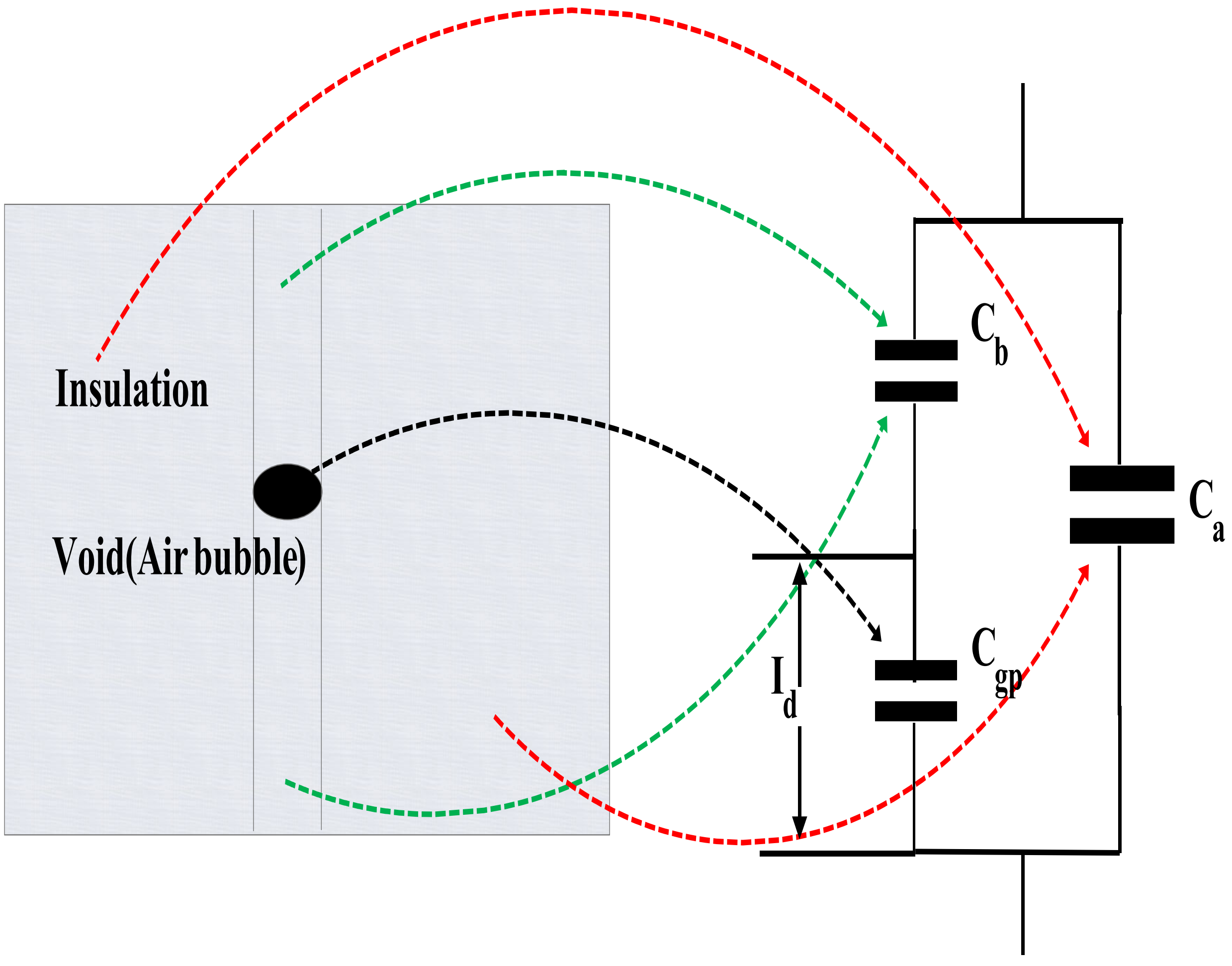


Figure 3.2: Electrical equivalent capacitance model for insulation with void

3.3 CIRCUIT FOR DETECTING PD SIGNAL IN WINDING INSULATION

As the void is created inside the transformer winding, a detection circuit is attached outside the winding in series with the void used measuring PD signal. The detection impedance can be either a resistive–capacitive (RC) OR resistive-capacitance-inductive (RCL) type. The RC type gives a unidirectional-pulse output, whereas the output for the RLC type is a damped oscillation [13].

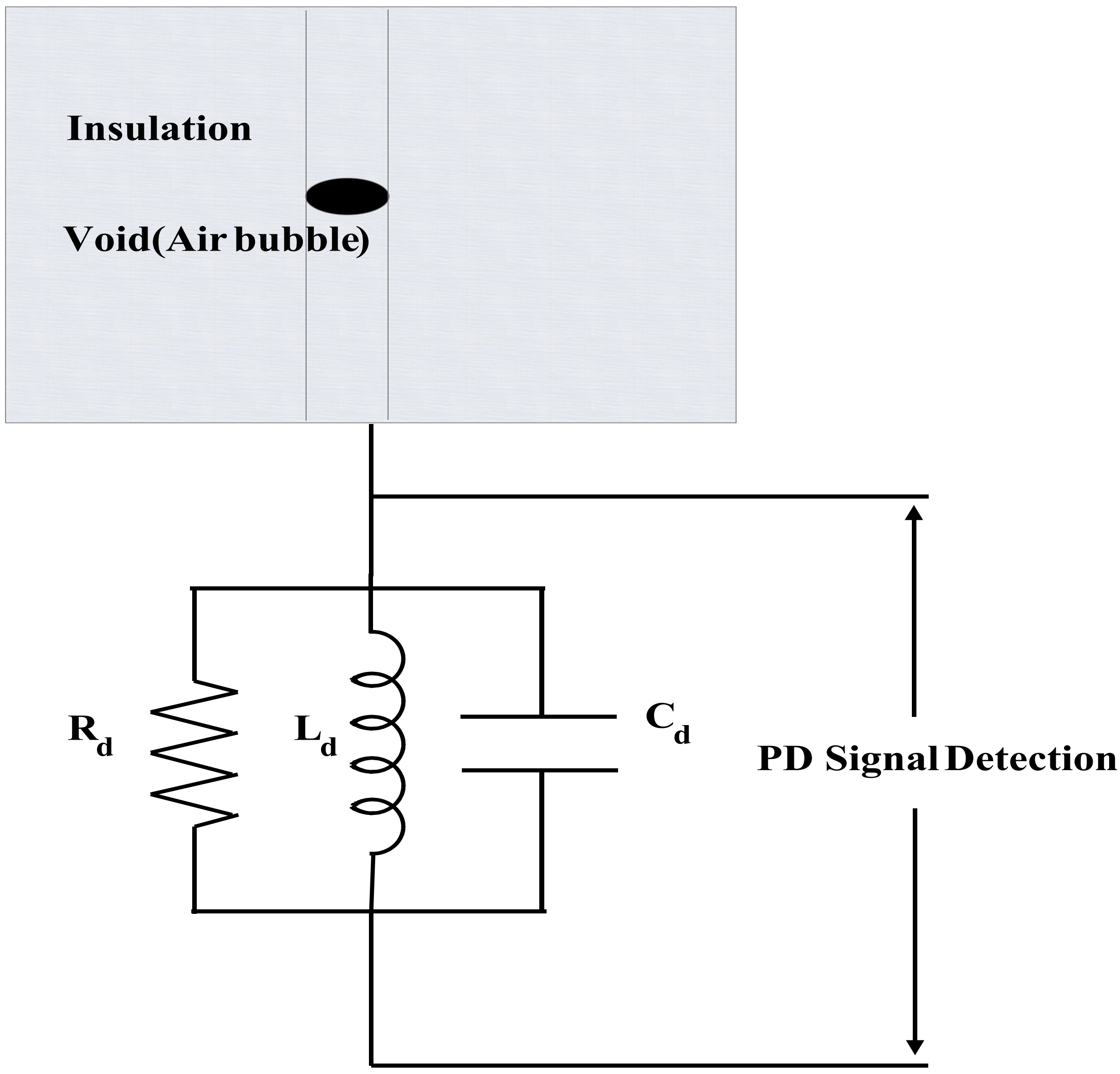


Figure 3.3: RLC type PD signal detection circuit

3.4 SIMULATION MODEL OF HIGH VOLTAGE TRANSFORMER WINDING

The simulation model represents a disc type winding which consists of 8 sections having internal winding series resistances (R), inductances (L), series and shunt capacitances(C_s, C_g), including the effect of their mutual inductances while the magnetic losses have been ignored [5].

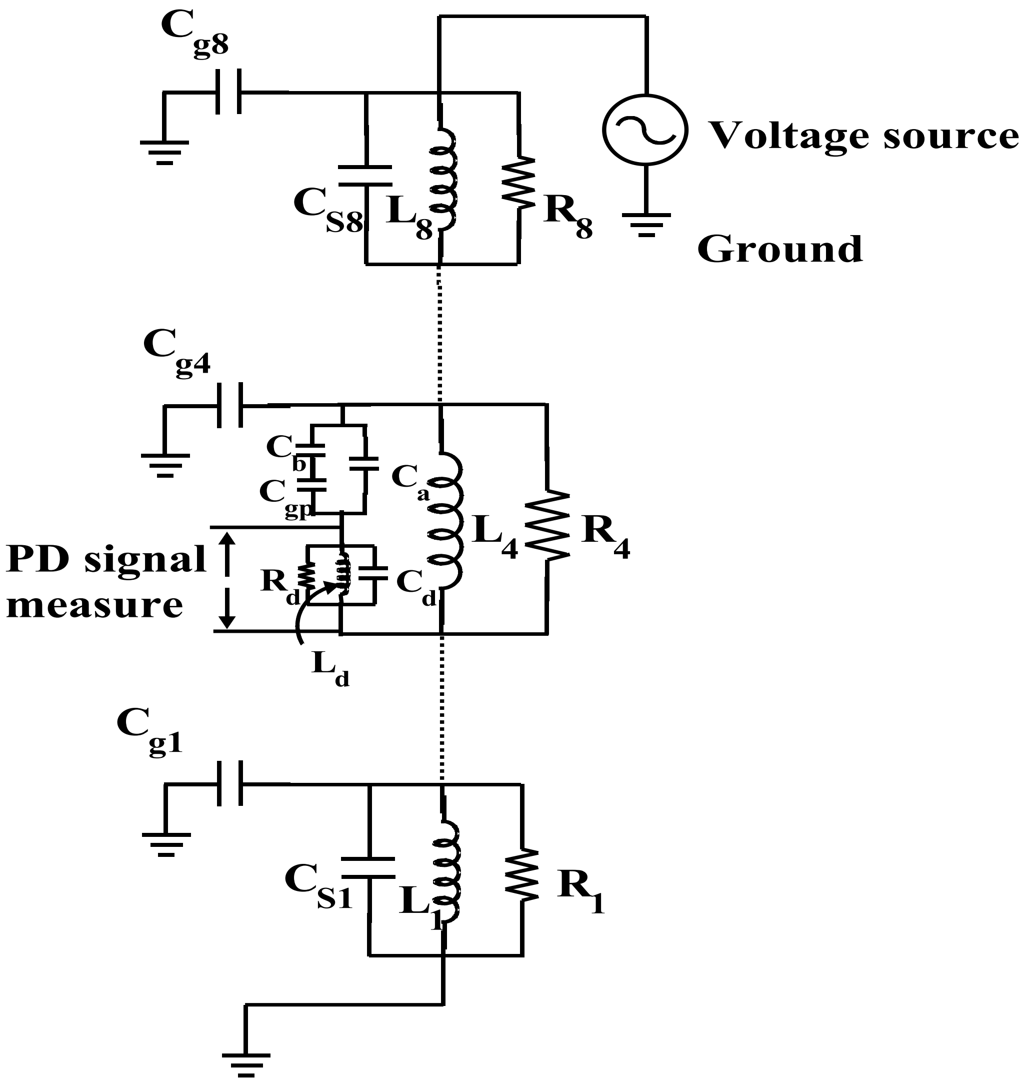


Figure 3.4: Electrical equivalent diagram of high voltage transformer winding with PD model and detection circuit

CHAPTER 4

SIMULATION RESULT AND DISCUSSION

Chapter-4
SIMULATION RESULT AND DISCUSSION

After assuring that PD models and transformer winding are correct, AC voltage is applied to the winding as the input signal. To simulate the PD activity inside the power transformer winding a MATLAB simulink model is considered in this work. In Fig.4.1 the applied voltage of 20 kV and along with the PD pulse is shown. InFig. 4.1to identify the position of the PDs with respect to phase angle. In Fig. 4.1It is observed that high amplitude PD pulse is appears on around 45 degree (negative pulse), 230 degree (positive pulse) and 315 degree (negative pulse). As it is well known that PD pulse amplitude is in milivolt or microvolt range, so to show the both graph in one plot, gain block is use with PD pulse measuring.

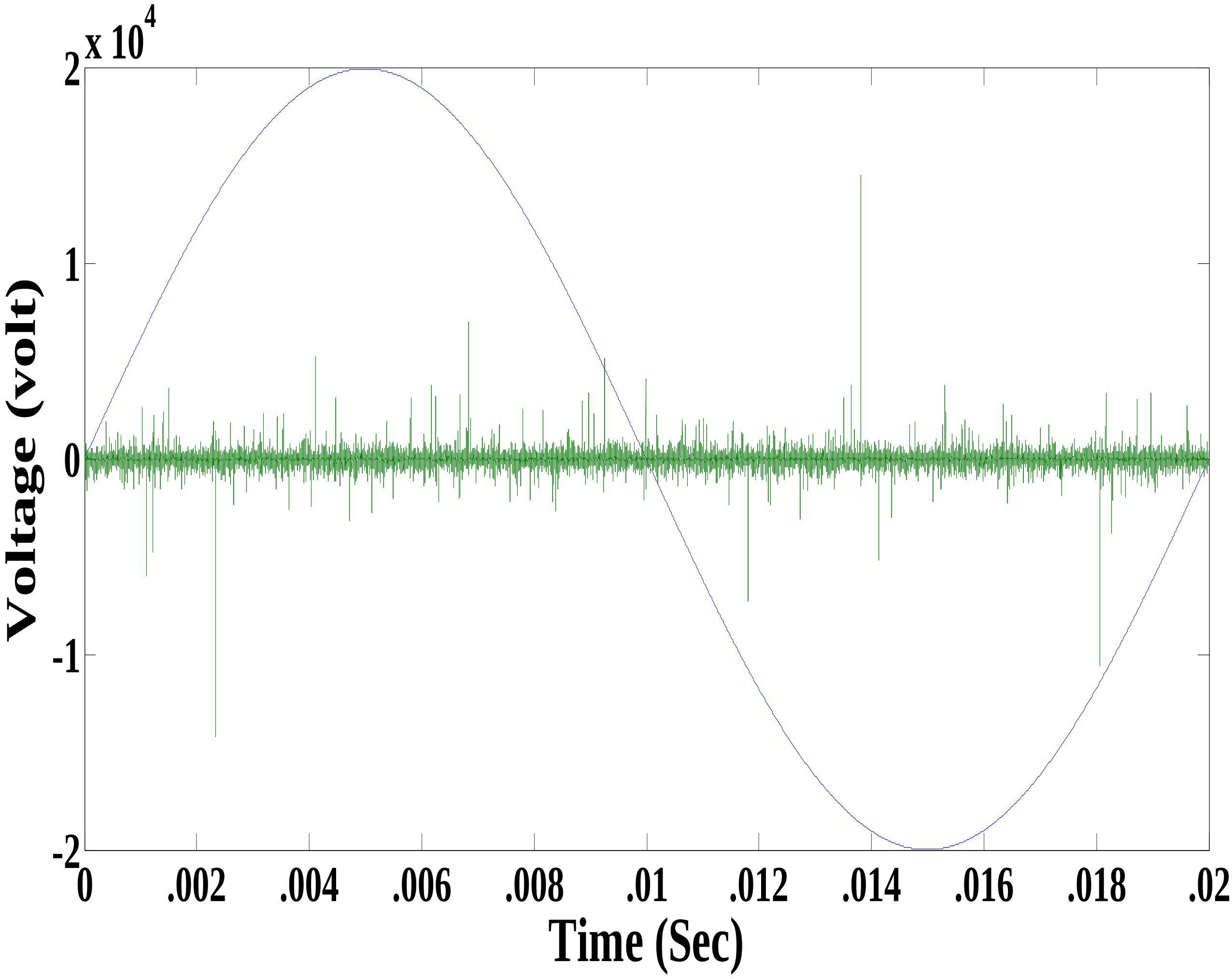


Figure 4.2: PD signal observed with 20 kV applied voltage

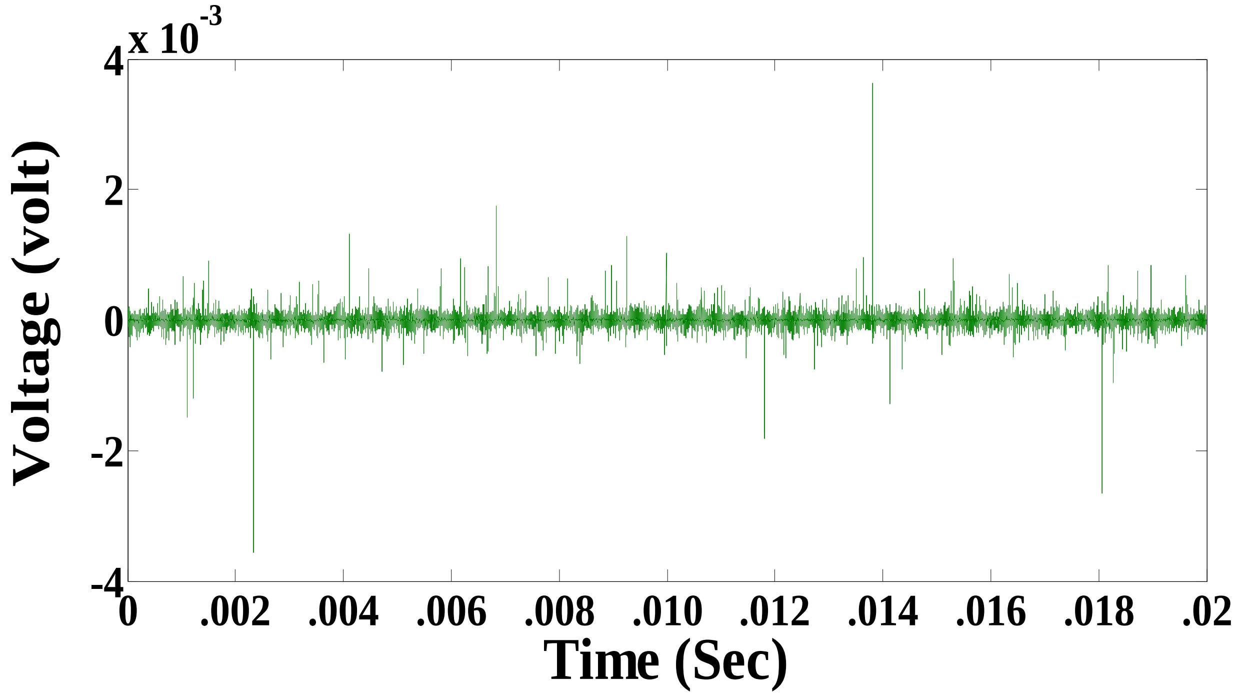


Figure 4.3: Observed PD signal from the developed simulation model with application of 20 kV

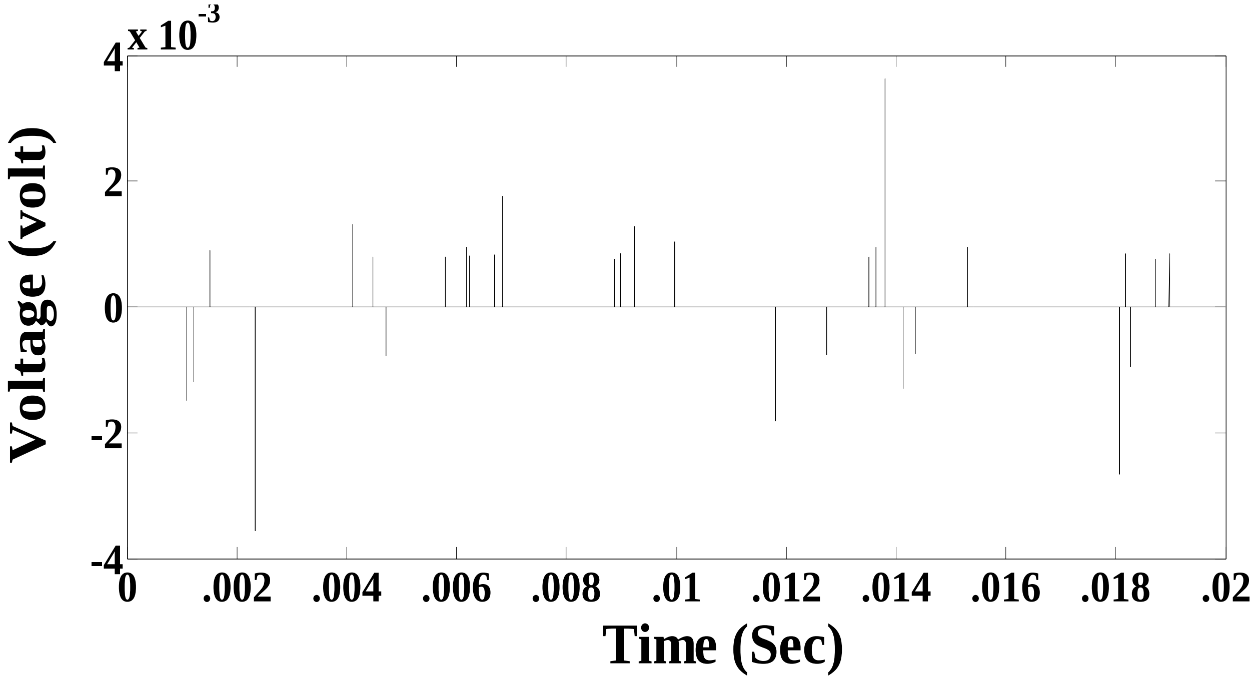


Figure 4.4: PD signal is extracted from the noisy raw signal

In Fig. 4.2 observed PD pulse in simulation model is shown. In this plot the high amplitude pulses are shown that the partial discharge is occurred in simulation model due to artificially created void inside the transformer winding of simulation model. In this PD signal along with PD pulses, noise is also there, so it has to be filtered out that noise signal. In Fig. 4.3 the de-noised PD pulse is shown.

In the simulation work the applied voltage of 20 kV and PD data are collected in time domain with a length of .02 sec. After that the analysis is done for the frequency contain by the PD signal. The PD data that are recorded are analysed with Fast Fourier Transform (FFT) and corresponding frequency spectrum of the PD signal is plotted which is shown in Figure. 8. It is seen that the number of frequency spectrum is found due to presence of PD pulse at different time instant. The range of frequency is 0 to 3.25 MHz. It is seen that in Fig. 4.4 different combination of frequency is present. Frequency that appears for this PD is fluctuating in nature because the random nature of PD pulse. It is also observed that the maximum amplitude of the frequency of the same PD pulse is appears at 2MHz so that it is a dominant frequency for PD pulse.

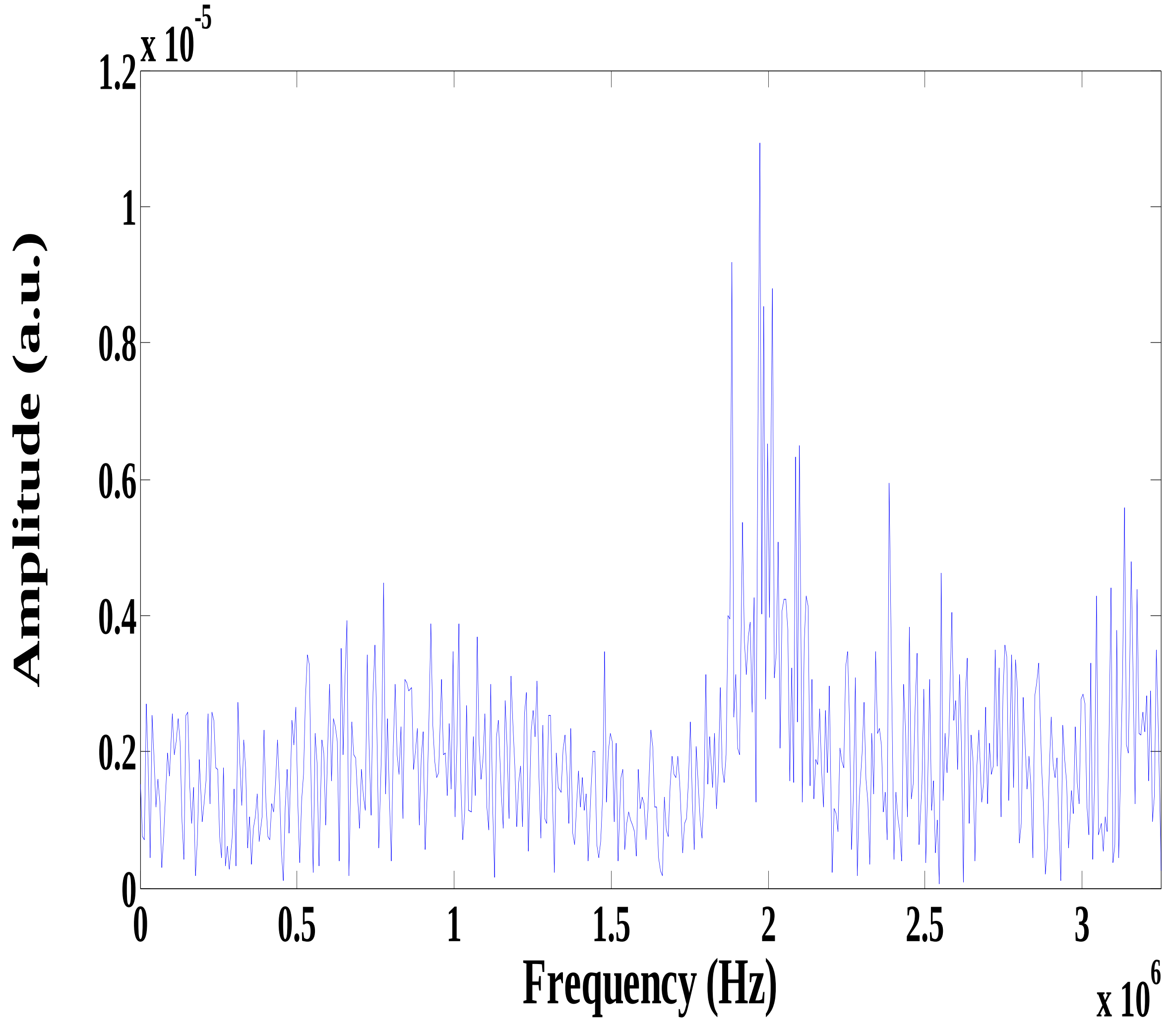


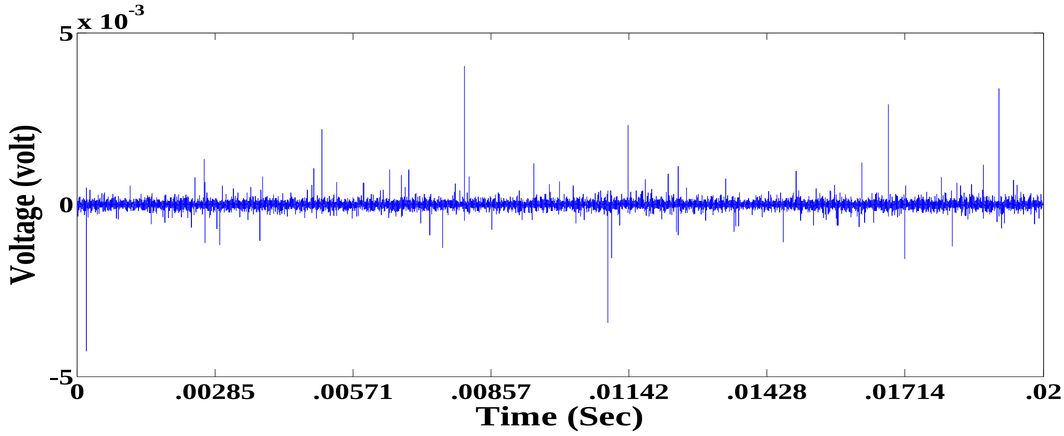
Figure 4.5: Frequency plot of observed PD pulse at 20 kV

Table 1: Rise time and fall time of PD pulses with amplitude variation of pulses

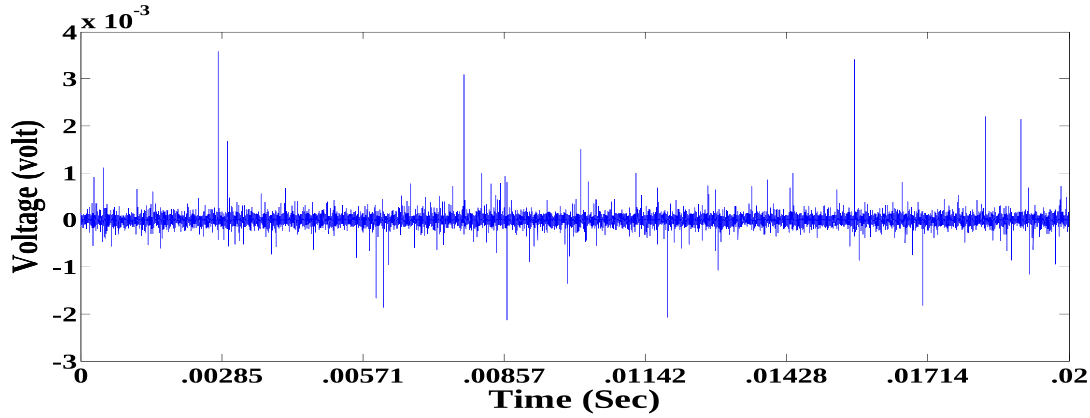
Pulse number	Duration of rise time (Sec)	Rise time (μSec)	Duration of fall time (Sec)	Fall time (μSec)	Amplitude (mV)
1	1.099831×10^{-3}-1.099991×10^{-3}	16.037	1.099991×10^{-3}-1.100152×10^{-3}	16.037	-1.5
2	1.227968×10^{-3}-1.228129×10^{-3}	16.037	1.228129×10^{-3}-1.228289×10^{-3}	16.037	-1.2
3	1.511025×10^{-3}-1.511185×10^{-3}	16.037	1.511185×10^{-3}-1.511346×10^{-3}	16.037	0.9
4	2.343998×10^{-3}-2.344158×10^{-3}	16.037	2.344158×10^{-3}-2.344318×10^{-3}	16.037	-3.5
5	4.110656×10^{-3}-4.110817×10^{-3}	16.037	4.110817×10^{-3}-4.110977×10^{-3}	16.037	1.3
6	4.486889×10^{-3}-4.487049×10^{-3}	16.037	4.487049×10^{-3}-4.487210×10^{-3}	16.037	0.79
7	4.722636×10^{-3}-4.722796×10^{-3}	16.037	4.722796×10^{-3}-4.722957×10^{-3}	16.037	-0.785
8	5.814770×10^{-3}-5.814930×10^{-3}	16.037	5.814930×10^{-3}-5.815091×10^{-3}	16.037	0.787
9	6.184267×10^{-3}-6.184427×10^{-3}	16.037	6.184427×10^{-3}-6.184588×10^{-3}	16.037	0.95
10	6.249057×10^{-3}-6.249218×10^{-3}	16.037	6.249218×10^{-3}-6.249378×10^{-3}	16.037	0.808
11	6.699222×10^{-3}-6.699382×10^{-3}	16.037	6.699382×10^{-3}-6.699542×10^{-3}	16.037	0.822
12	6.852217×10^{-3}-6.852377×10^{-3}	16.037	6.852377×10^{-3}-6.852537×10^{-3}	16.037	1.755
13	8.878999×10^{-3}-8.879159×10^{-3}	16.037	8.879159×10^{-3}-8.879320×10^{-3}	16.037	0.753
14	8.991259×10^{-3}-8.991420×10^{-3}	16.037	8.991420×10^{-3}-8.991580×10^{-3}	16.037	0.839
15	9.258760×10^{-3}-9.258920×10^{-3}	16.037	9.258920×10^{-3}-9.259081×10^{-3}	16.037	1.286
16	9.996952×10^{-3}-9.997113×10^{-3}	16.037	9.997113×10^{-3}-9.997273×10^{-3}	16.037	1.029
17	11.816694×10^{-3}-11.816855×10^{-3}	16.037	11.816855×10^{-3}-11.817015×10^{-3}	16.037	-1.82
18	12.760163×10^{-3}-12.760323×10^{-3}	16.037	12.760323×10^{-3}-12.760484×10^{-3}	16.037	-0.760
19	13.534921×10^{-3}-13.535081×10^{-3}	16.037	13.535081×10^{-3}-13.535241×10^{-3}	16.037	0.793
20	13.652954×10^{-3}-13.653115×10^{-3}	16.037	13.653115×10^{-3}-13.653275×10^{-3}	16.037	0.957
21	13.832731×10^{-3}-13.831448×10^{-3}	16.037	13.831448×10^{-3}-13.831609×10^{-3}	16.037	3.629
22	14.150268×10^{-3}-14.150429×10^{-3}	16.037	14.150429×10^{-3}-14.150589×10^{-3}	16.037	-1.288
23	14.377355×10^{-3}-14.377515×10^{-3}	16.037	14.377515×10^{-3}-14.377676×10^{-3}	16.037	-0.7469
24	15.329003×10^{-3}-15.329163×10^{-3}	16.037	15.329163×10^{-3}-15.329324×10^{-3}	16.037	0.945
25	18.093978×10^{-3}-18.094138×10^{-3}	16.037	18.094138×10^{-3}-18.094298×10^{-3}	16.037	-2.654
26	18.213936×10^{-3}-18.214096×10^{-3}	16.037	18.214096×10^{-3}-18.214257×10^{-3}	16.037	0.839

27	18.306150×10^{-3}-18.306310×10^{-3}	16.037	18.306310×10^{-3}-18.306471×10^{-3}	16.037	-0.951
28	18.762889×10^{-3}-18.763050×10^{-3}	16.037	18.763050×10^{-3}-18.763210×10^{-3}	16.037	0.759
29	19.004730×10^{-3}-19.004891×10^{-3}	16.037	19.004891×10^{-3}-19.005051×10^{-3}	16.037	0.838

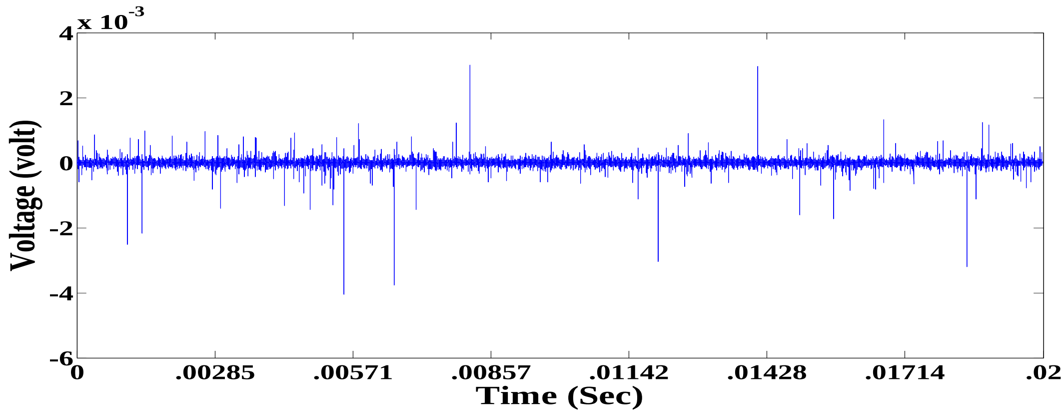
In Fig. 4.3twenty nine (29) number of PD pulses are there with positive and negative amplitude. In Table 1twenty nine (29) number of PD pulse is taken for comparing their rise time and fall time in μSec. And also the amplitude of pulse that is varies from positive to negative voltage.



(a)



(b)



(c)

Figure 4.6: Observed PD pulse for 20kv supply voltage for 20 turns in winding when PD is created in (a) 4th (b) 13th (c) 17th turn

From the Fig. 4.5 it is seen that the magnitude of the PD pulse is decreases, when PD model is shifted from the 4th turn to the 17th turn in transformer winding. From this result it is analyses that when the fault is near to supply side the PD pulse magnitude is high and when it moves away from the supply end its magnitude decreases.

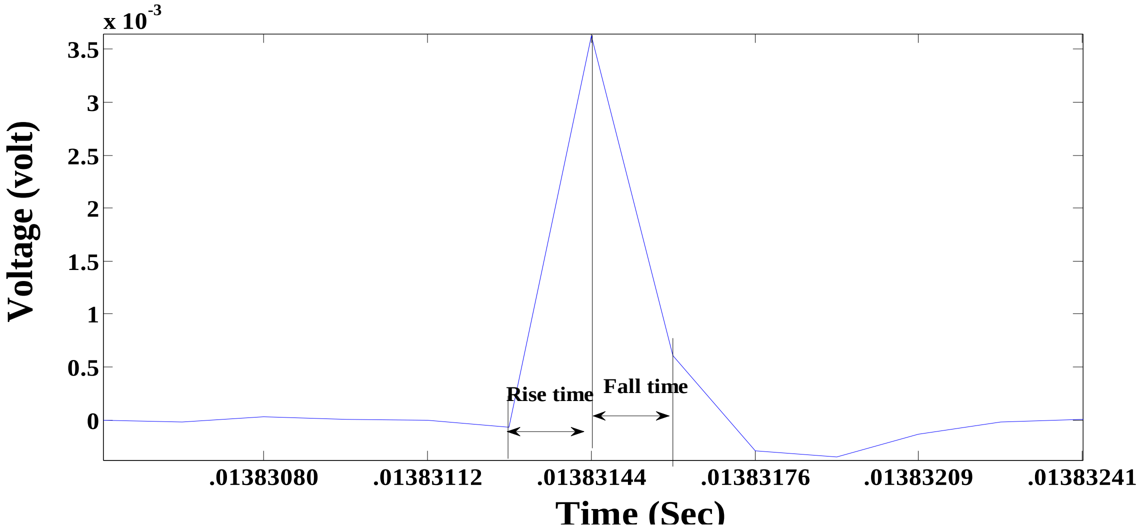


Figure 4.7: Rise time and fall time of observed PD pulse

In Fig. 4.6 Rise time and fall time of one PD pulse is shown. Rise time and fall time of each pulse is same. Rise time is 16.037 µSec and fall time is 16.037 µSec. Total width of the pulse is 32.074 µSec.

CHAPTER 5

PARTIAL DISCHARGE DETECTION USING ACOUSTIC EMISSION TECHNIQUE IN MODEL TRANSFORMER

Introduction

AE sensor

Experimental setup

Results and discussions

Chapter-5
PARTIAL DISCHARGE DETECTION USING ACOUSTIC EMISSION TECHNIQUE IN MODEL TRANSFORMER

5.1 INTRODUCTION

Acoustic emission is the process by which sound is produced by rapid energy release inside a material. It is possible to listen to this release of energy as a sound wave propagates through the surrounding media [15]. The received waveform depends on the nature of both the source and the materials through which the wave passes. Consequently PD generation is distinguishable with respect to the assumed discrimination threshold. Measurements are performed by attaching transducer to the model transformer tank and recording the acoustic pulse on a transient analyzer.Acoustic PD detection has following advantages over electrical methods: (i) acoustic method is immune to electromagnetic interference (EMI), hence can be applied for online detection and (ii) acoustic method can provide an indication of PD source location within a complex system like transformer [18]. Different methods of source location exist to locate the PD source from all acoustic measurements or simultaneous electrical and acoustic measurements.

ACOUSTIC EMISSION INSTRUMENTATION

Typical AE tools consist of the following components:

- Sensors used to detect AE events.
- Preamplifiers amplifies initial signal. Typical amplification gain is 40/60 dB.
- Cables transfer signals on distances up to 20m to AE devices. Cables are normally of coaxial type.
- Data acquisition device perform filtration, signals' parameters evaluation, data analysis and charting.

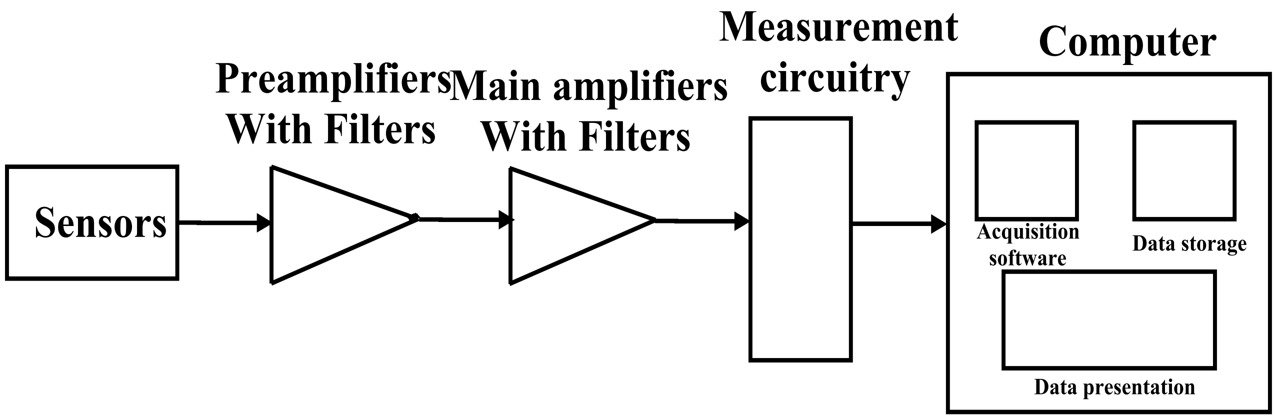


Figure 5.1: Block diagram representation of acoustic emission instrumentation

5.2 AE SENSOR FOR PD DETECTION

The PK15I sensor is a medium frequency-resonant, acoustic emission sensor with an integral, ultra low noise, low power, filter, 26dB preamplifier, which can drive up to 20 meters of cable. This new sensor represents an enhancement in both noise and low power consumption performance, with noise level below 3 µV and power utilization of 25 mW. The PK15I features a well-built stainless steel, integrated body structure. Sensor is smaller size and the same frequency response as the R15I sensor. The integrated Auto Sensor Test (AST*) capability allows these sensors to pulse as well as receive. This quality lets you verify the sensor coupling and performance at any time.

Figure 5.2: Acoustic emission Sensor for PD detection

This sensor is used for PD detection in the experimental setup. The front part of the is made with Ceramic material and the case is made with stainless steel. Other physical, electrical, dynamic and environmental detail is given in the table 2. In Fig. 5.3 the dimension of the sensor is given, in that height, radius and other things are given.

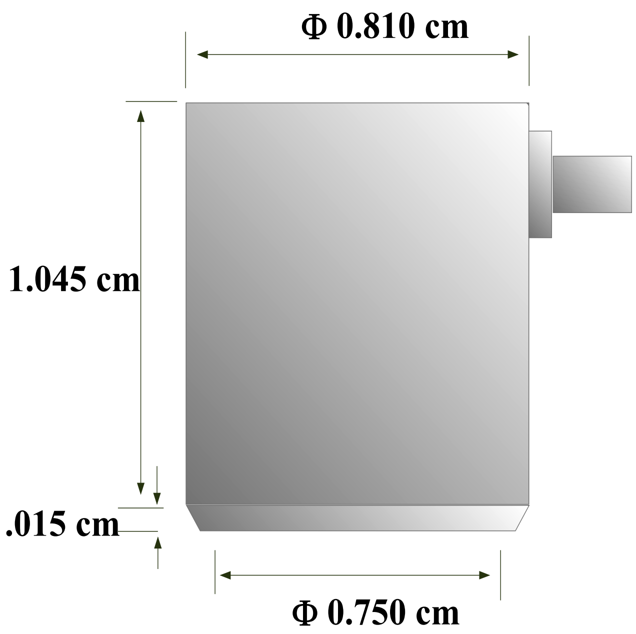


Figure 5.3: Dimensions of sensor used for PD detection

Figure 5.4 shows the power/signal connection diagram. This diagram shows how the sensor is work and which electrical component is there. In this circuit diagram two resistors and two capacitors are connected as shown.

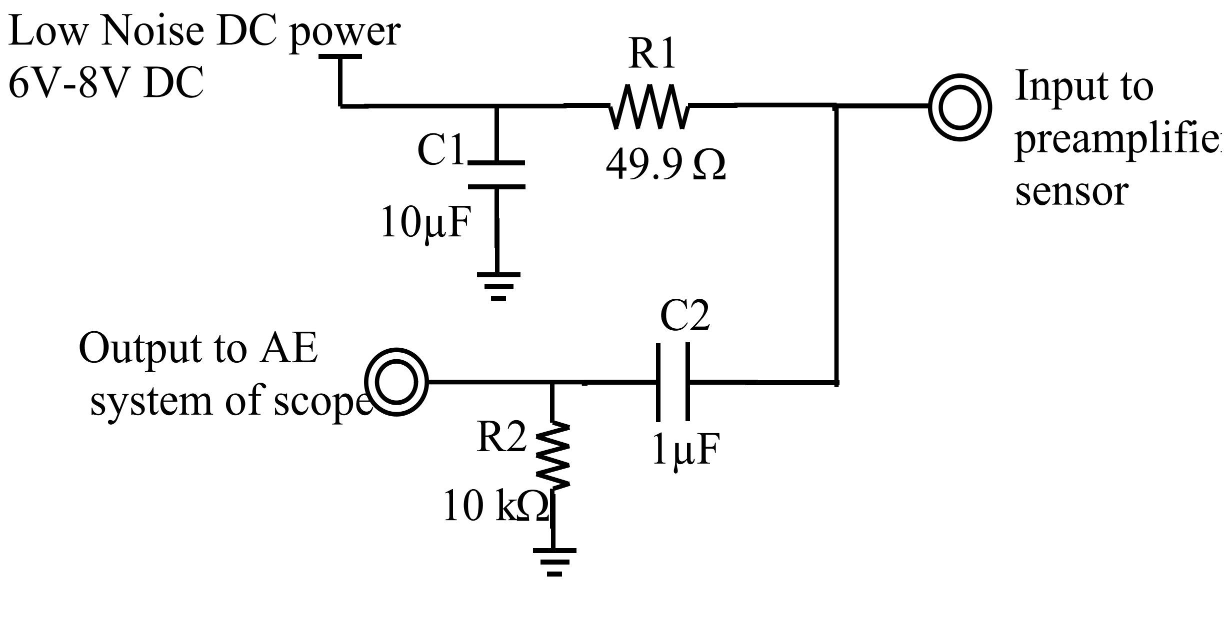


Figure 5.4: Power or signal connection diagram of sensor

5.2.1 OPERATING SPECIFICATIONS OF AE SENSOR

Table 2: Operating specification of PD detection sensor

DYNAMIC	
Peak Sensitivity, Ref V/µbar	-36 dB
Operating Frequency Range	100-450 kHz
Resonant Frequency, Ref V/µbar	150 dB
Directionality	±1.5dB
ENVIRONMENTAL	
Temperature Range	-35 to 80°C
Shock Limit	500 g
PHYSICAL	
Dimensions	0.81" dia x 1.06" h (20.6 x 27 mm)
Weight	51 grams
Case Material	Stainless Steel
Face Material	Ceramic
Connector	SMA
Connector Locations	Side
ELECTRICAL	
Gain	26 dB
Power Requirements	4-7 VDC @ 5 mA
Operating/Max Current	5/35 mA
Noise Level (RMS RTI)	< 3 µV

5.2.2 AE PARAMETERS

In Fig. 5.5, the peak amplitude refers to the maximum of AE signal while the energy is defined as the integral of the rectified voltage signal over the duration of the AE hit. The duration in the graph is the amount of time from the first threshold crossing to the end of the last threshold crossing.

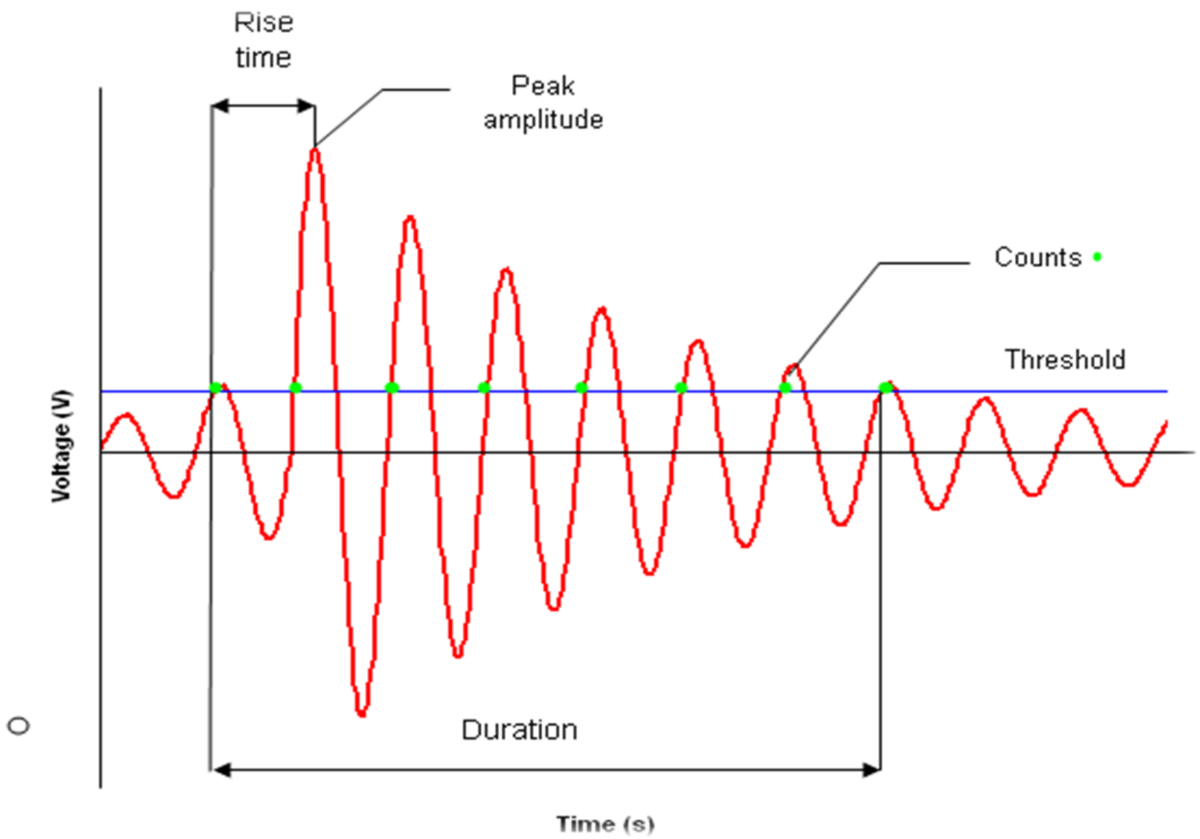


Figure 5.5: Different features of single PD pulse

Counts are equivalent to the number of AE signals that exceed threshold while the count rate gives the number of counts per unit time. The rise time is the time from the first threshold crossing to the maximum amplitude and the average frequency is the AE counts upon the entire duration as shown below:

$$A.F = \frac{AE\,counts}{Duration}\,[kHz]$$

5.2.3 PROPAGATION PATH OF PD SIGNAL

In Fig.5.6 shows that how the signals are travelling in the model transformer tank. In Fig. 5.6 PD source is there from that source three path follow by the signal. The first one is the direct acoustic path; it is a path that travels directly from source to the sensor [8]. The second one is the primary reflection path, this path ravel the direction as shown. The third one is the structure born path that travels from outer layer of the tank to the sensor. The acoustic signal follows this path to get the signal to the sensor, which is the reason that signals are not pure PD signal. That PD signal is contain noise signal with it.

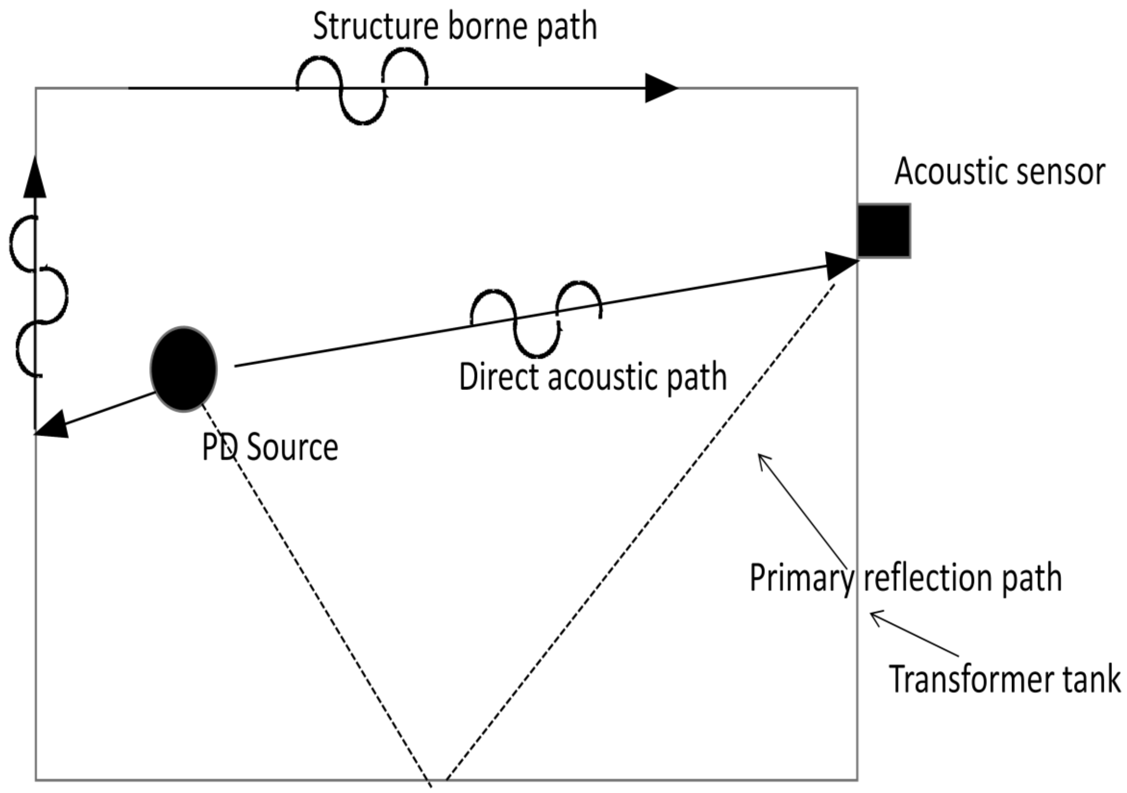


Figure 5.6: Illustration of typical propagation paths for the acoustic PD signal

5.3 EXPERIMENTAL SETUP

An experiment was conducted on a model transformer tank of 25 cm × 20 cm × 15.5 cm in size filled with transformer oil. A schematic diagram of the experimental model is shown in Fig. 5.7. For detection of partial discharge signal there are three types of configuration, namely point-plane, rod-plane and plane-plane electrode system. Point–plane electrode systems are used to model the PD on conductor protrusions in a transformer. One 100-450 kHz range resonant peak type piezoelectric sensors are employed for the work. The sensor is fixed on the tank surface using tape on and grease as an acoustic couplant is used in between sensor and tank to have better acoustic contact. Since these algorithms do not require any specific relative position of sensor and source, the sensor and source are positioned arbitrarily.

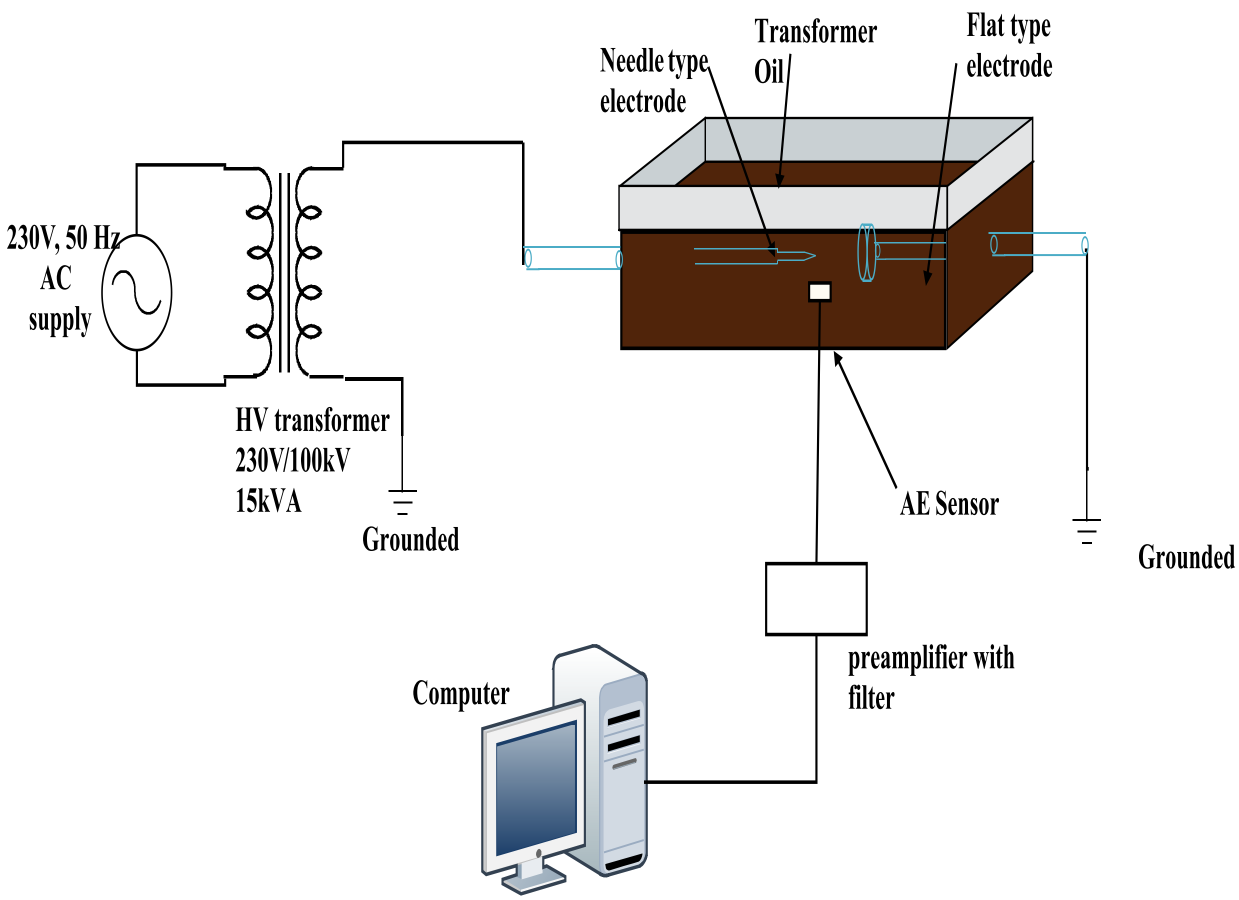


Figure 5.7: Schematic diagram of the experimental transformer model

5.4 RESULTS AND DISCUSSIONS

From Fig. 5.8 it can be seen that the AE signal is not initiated until the supply voltage of the experimental setup reaches more than 40 kV. It is observed that the supply voltage reaches this value after 96 s and therefore there are no amplitude hits seen between 0 and 96 s. After 96 s, the supply voltage signal reaching the transformer oil reaches 45 kV which results in induction of hits to the sensor surface as seen in the graph.

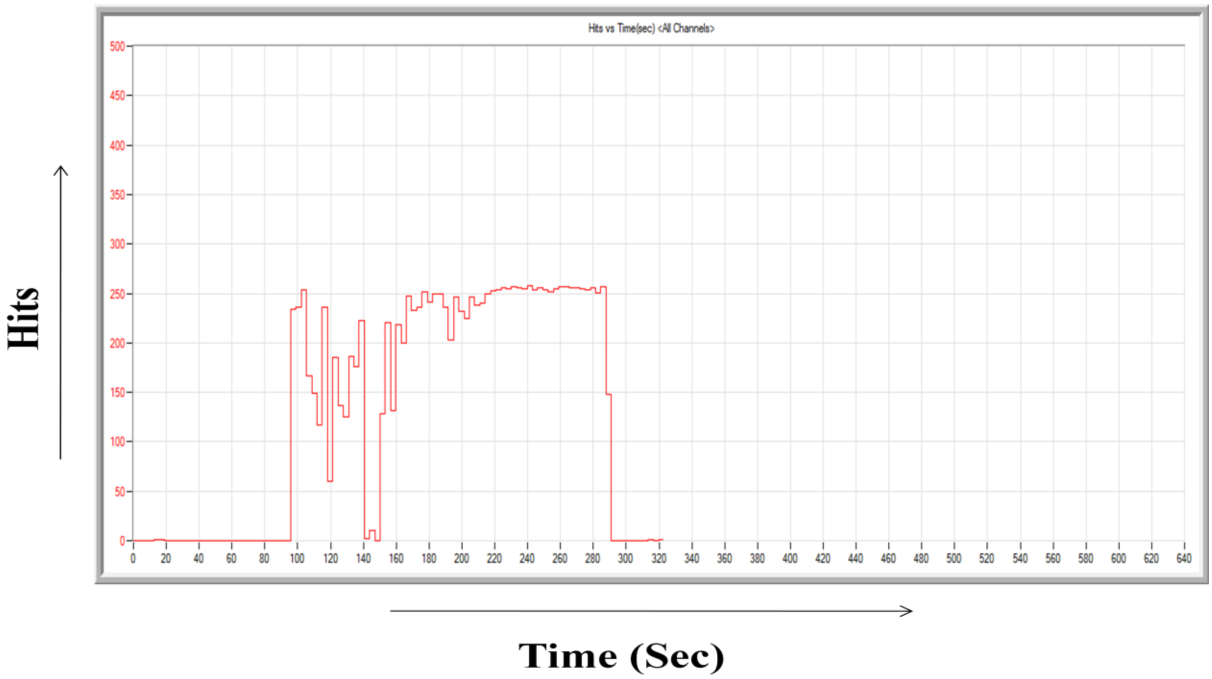


Figure 5.8: Change in hits amplitude with respect to time

The AE signal is variable at the supply voltage of 45 kV and thus the signal reaching the sensor shows large variations which also gets reduced to zero. Due to this reason, when the supply voltage was increased to 50 kV AE signal became stable and thus minute variations were observed in the signal hits. At this point, the signal hits showed a constant value around 250.

Table 3: The PD pulse found at different supply voltage

Voltage (kV)	Time (Sec)	Waveform (No.)
45	96.09-150.49	1-2498(PD pulse)
50	150.50-290.08	2499-12943(PD pulse)

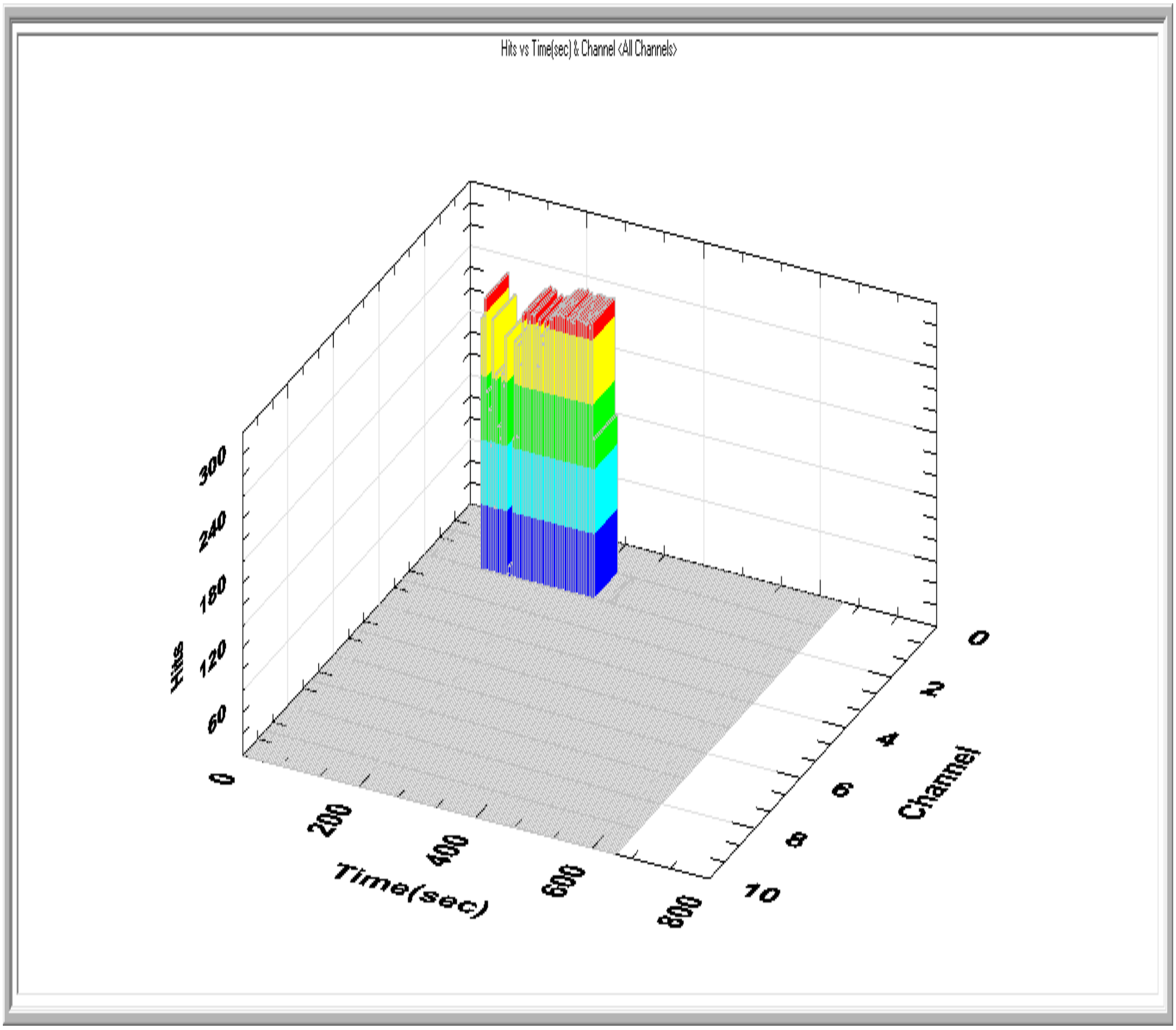


Figure 5.9: Change in hits amplitude with respect to time for channel 1

Figure 5.9 is the 3D graphical representation of the variation in the hits amplitude with respect to time as shown in above Fig 5.7. The 3D histogram is plotted to indicate that the original variables are continuous in nature. This graph represents the tabulated hits shown as adjacent rectangles in discrete intervals. The area of the rectangle is equivalent to the hits observed in that particular interval and the height shows the amplitude of hits observed. From this fig. also it can be concluded that until the supply voltage reaches 40 kV, the amplitude hits are not initiated which happens till 90s. The AE signal becomes stable after the supply voltage reaches the value of 50 kV and thus the amplitude seen is around 250.

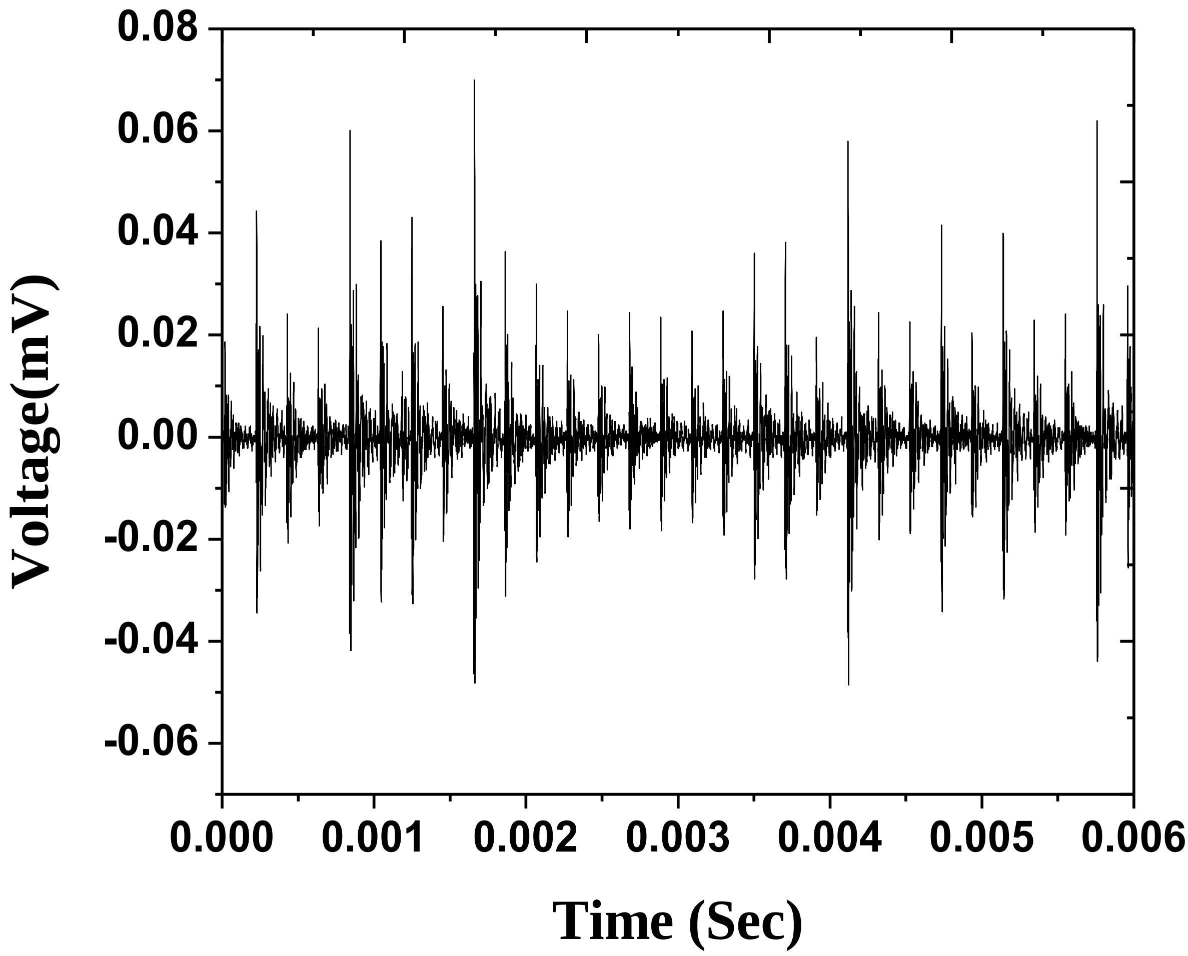


Figure 5.10: Change in voltage with respect to time curve when 32 PD pulse data is taken

Figure 5.10 shows the generation of PD pulses as the change in voltage with respect to time. From the experiment conducted multiple PD pulses were generated which were shown in the graph. Here the multiple data are taken to plot the PD pulse variation. To observe the PD activity in model transformer this plot is drawn. It is seen from the graph that the pulse are random in nature not gradually increase or decrease as known by the PD phenomena. From this graph it is seen that the amplitude of the voltage of PD pulse is very low and it is in milivolt range.

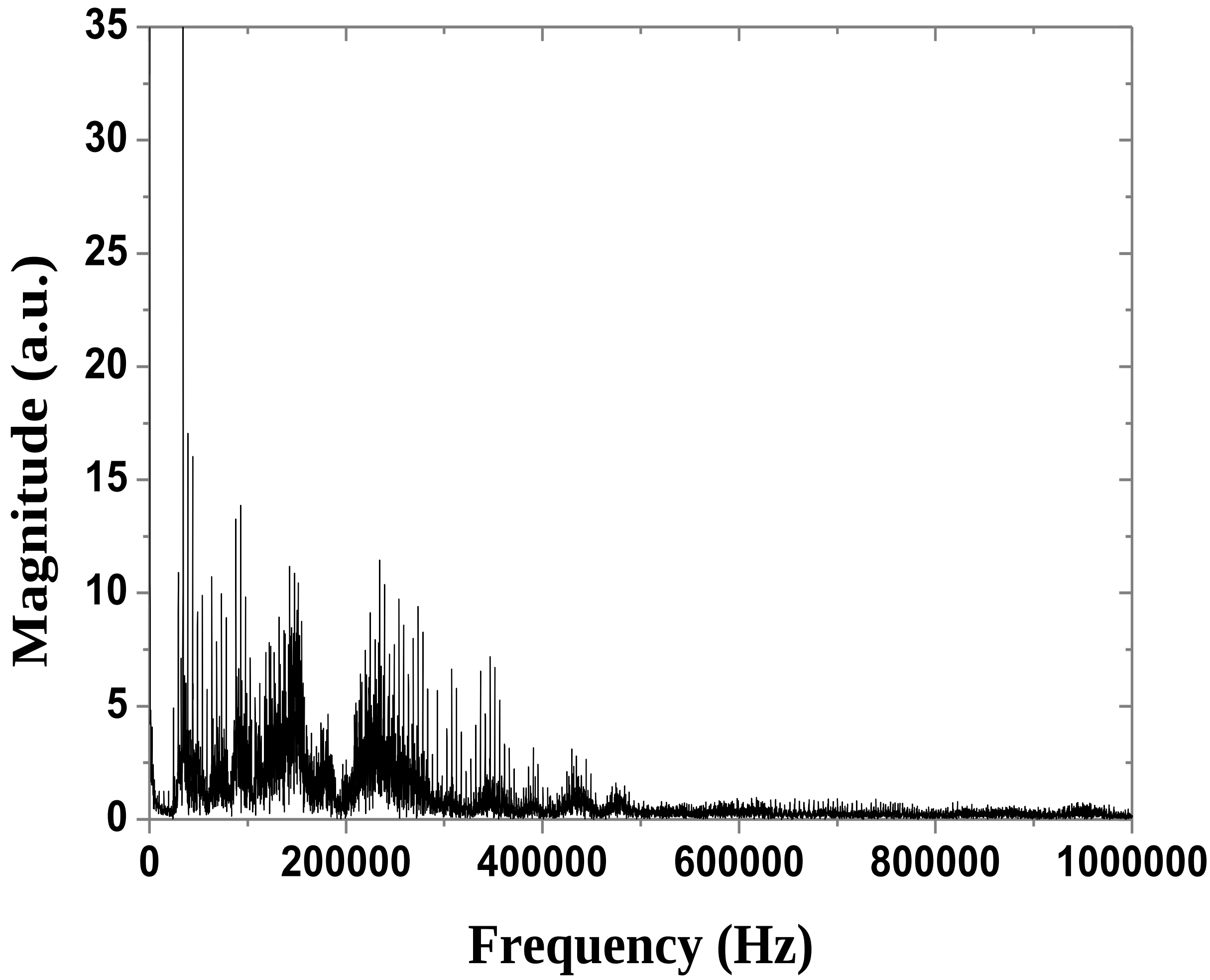


Figure 5.11: Frequency response of multiple PD signal

In this Fig. 5.11 the frequency response of the Fig.5.10 in this graph lots of PD pulses are their that's why the lots of frequencies are present. Here the dark part shows that different pulses have same frequency. Because of random nature of PD pulse frequency is also varies from 0-400 kHz. And the dominating frequency is 45 kHz.

Experimental data for Partial discharge in model transformer

Table 4: AE signal hits to the sensor

Total AE hits	12954
Total TDDs	831
Total waveforms	12954
Total resume	1

Table 5: Different features of experimental data

Feature	Channel	Minimum	Maximum	Average	StdDev
Rise time	1	1.0000	508.0000	4.5368	26.3945
Counts	1	1.0000	652.0000	5.9429	7.6856
Energy	1	0.0000	224.0000	1.9395	3.6283
Duration	1	1.0000	5928.0000	72.1204	102.9736
Amplitude	1	42.0000	70.0000	57.7678	6.1480

In table 4 the data is given for the AE signal reach to the sensor. According to that data AE signal that travel in the model transformer tank is reach to the sensor 12954 times. And for each hit to the sensor it generates one waveform. At the time of experiment the resume is done at once. And in table 5 different features of experimental data is shown. Data are for total 12954 AE hits. This table shows the different features like rise time, counts, energy, duration and amplitude. And their maximum and minimum value, the average of total data and the standard deviation from average value.

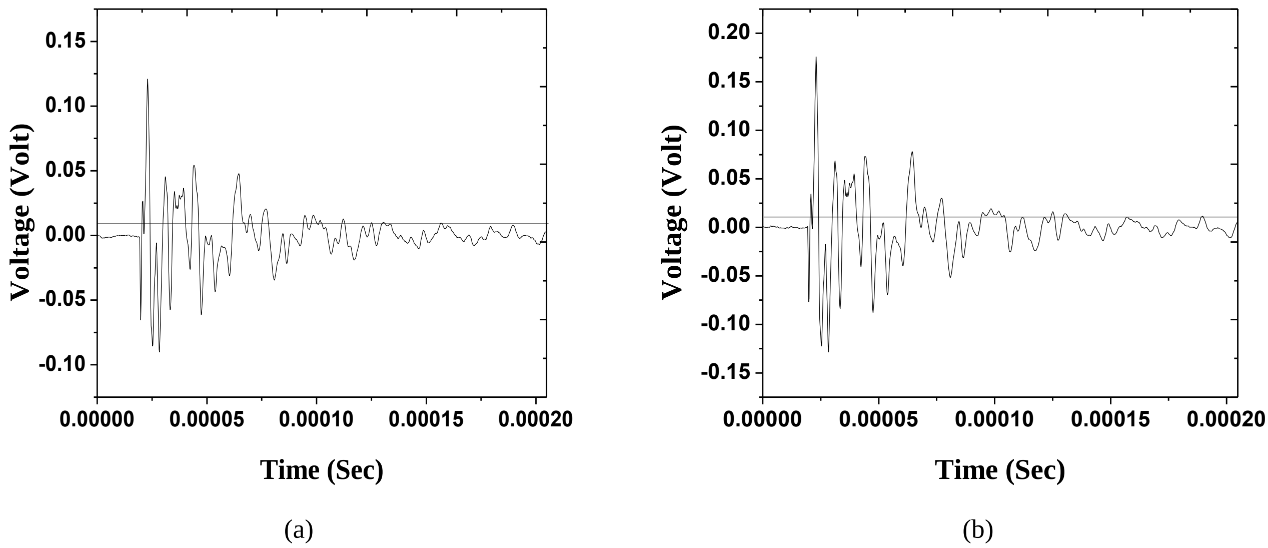


Figure 5.12: (a) Change in voltage with respect to time curve for single PD pulse at 45 kV (b) Change in voltage with respect to time curve for single PD pulse at 50 kV supply voltage.

This PD pulses are selected on because it has a highest magnitude of voltage among all the pulses in between their range. In table 6 AE parameters are calculated for this PD pulses. This shows the comparison of two PD pulses of different supply voltage. From this table it is observe that when the supply voltage is increases the peak amplitude, threshold amplitude and duration is increases. But the preamplifier gain, rise time and average frequency are decreases.

Table 6: Comparison of PD pulses on different supply voltage

SL. No.	AE parameter	45 kV supply	50 kV supply
1	Peak amplitude	0.119803121 volt	0.1761660885 volt
2	Preamplifier gain	101.56 dB	104.92 dB
3	Counts	11	10
4	Threshold amplitude	.00961309665 volt	.0151119913 volt
5	Rise time	0.25551639×10^{-5} Sec	0.24285502×10^{-5} Sec
6	Duration	9.09171931×10^{-5}Sec	1.045630651×10^{-4}Sec
7	Average Frequency	120. 989 kHz	95.636 kHz

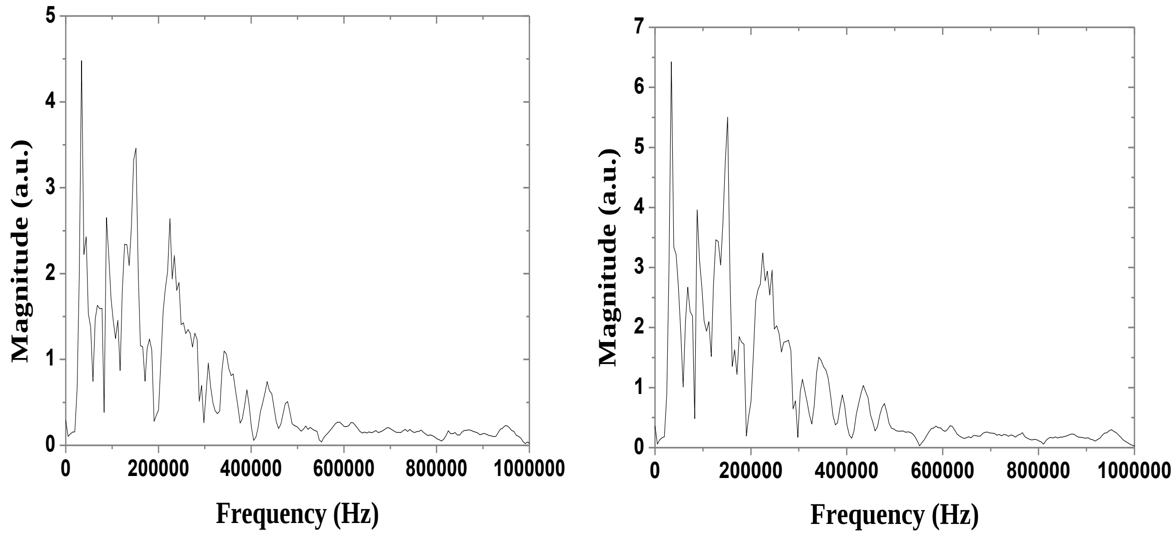


Figure 5.13: (a) Observed frequency plot for single PD pulse at 45kV supply voltage (b) Observed frequency plot for single PD pulse at 50 kV supply voltage

Figure 5.13 (a) shows frequency plot of the PD pulses shown in Fig. 5.12, from this figure it is observed that the variation in frequency in between 12.5-500 kHz. It can be observed that the PD pulses are highly variable in nature because the PD phenomenon is random. The variations are observed in the range of 12.5 kHz to 500 kHz after which the pulses become slightly stable. The dominant frequencies are at 50 kHz, 150 kHz and 210 kHz. But when the comparison is done between Fig. 5.13 (a) and (b) not much change in the frequency curve but the main thing is change in their magnitude, in 50 kV supply voltage PD pulse magnitude is higher than the PD pulse taken in between the range of 45 to 50 kV supply voltage.

ADVANTAGES

Compared to usual inspection methods the advantages of the Acoustic Emission technique are:

- High sensitivity.
- Early and quick detection of defects, flaws, cracks etc.
- Real time monitoring
- Cost Reduction
- Defective area location: only critical defects provide sustainable Acoustic Emission sources.
- Minimization of plant downtime for assessment, no need for scanning the whole structural surface.
- Minor disturbance of insulation.

CHAPTER 6

CONCLUSION AND SCOPE FOR THE FUTURE WORK

Conclusion

Scope for the future work

Chapter-6
CONCLUSION AND SCOPE FOR THE FUTURE WORK

6.1 CONCLUSION

To understand the PD phenomena inside the transformer practical and simulation model has been developed in this work. MATLAB based simulink model is developed and maximum PD magnitude, number of PDs and other PD interrelated parameters are observed. In this work it is identify that on which phase angle of supply voltage the PD pulse amplitude is high. It is also observed that the range of PD pulse amplitude is in milivolt and microvolt range. In this work the de-noising of observed PD pulse is also done. Frequency of the observed PD pulse is also observed and find out the dominant frequency. Rise time and fall time of observed PD pulse is calculated with amplitude variation of pulse. A change in PD pulses is also observed when PD model is changed from turn to turn. It is find out that magnitude is decreases when PD model is shifted away from the supply side. The experiments are conducted on a model transformer tank filled with transformer oil. By using the acoustic emission technique PD pulses are observed. And different features of experimental data for different supply voltage like threshold amplitude, rise time, preamplifier gain and duration of PD pulse are investigated. This study will help to power engineers to predict the condition of transformer winding.

6.2 SCOPE FOR THE FUTURE WORK

- Detection of PD activity inside the transformer winding using different detection technique which helps the early diagnosis of such transformer winding for increase their reliability and life time.
- Research can be carried out in future to find out the exact location of PD in transformer winding.

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